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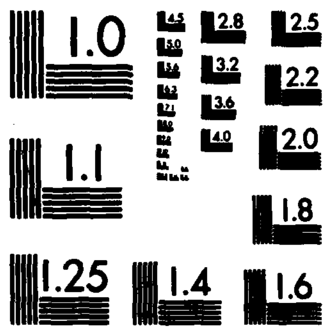

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AIDS TO NAVIGATION PRINCIPAL FINDINGS REPORT: IMPLEMENTATION AS A TEST OF DRAFT DESIGN MANUAL

Eclectech Associates Division of
Ship Analytics, Incorporated
North Stonington Professional Center
North Stonington, Connecticut 06359

April 1985

Interim Report

Prepared for

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16. Abstract

The research reported here is part of the United States Coast Guard's Performance of Aids to Navigation (AN) Systems Project. The objective of the project is to provide guidelines for evaluation and design of AN systems in restricted waterways. The major effort has been the evaluation of aid systems under a variety of conditions on a marine simulator developed for the project at Ship Analytics, Inc., North Stonington, Connecticut.

This report describes the Implementation task which was designed to experimentally test the draft manual's guidelines for evaluation and design of AN systems in restricted waterways. The Upper Narragansett Bay near Providence, Rhode Island, was the channel in which the draft manual's recommendations were implemented. Data was primarily collected at sea in both the original and modified channel. The at-sea data collection electronically tracked 30,000 dwt tankers inbound in the Upper Narragansett Bay. Data was also collected on the marine simulator developed for the project at Ship Analytics, Inc., North Stonington, Connecticut.

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The implementation task was possible only because of the involvement and cooperation of a great many people outside of Ship Analytics. We would like to thank them all. There were more than we can recall and acknowledge individually.

The at-sea data collection effort required cooperation and logistical support from many directions. In conjunction with the Coast Guard, Ship Analytics would like to express appreciation to some of those groups and individuals who made the data collection project on Narragansett Bay possible. They included the pilots, dispatchers, and pilot boat operators of the Northeast Marine Pilots, Inc., whose assistance in meeting the vessels and cooperation in accommodating data collection requests at sea were central to the completion of the project. They also included the oil companies, especially Mobil and Texaco, who allowed Ship Analytics' data collection teams to board their tanks; the masters and crew members of the tankers themselves who gave their cooperation and hospitality; and the office personnel at the pier site who provided advance scheduling information on ship arrivals.

We want to thank the Northeast Marine Pilots, Incorporated of Newport, Rhode Island for more than their cooperation at sea. We have been heavily dependent on them as consultants and as pilots for the simulator experiments as well. The simulator evaluation of possible aid systems for Narragansett Bay could not have been done without the cooperation and participation of the local pilots. We are especially indebted to Captain Kenneth Warner, President, who has expended considerable time and effort to meet our needs.

Ship Analytics would like to thank all the United States Coast Guard personnel who were connected with the complex implementation process. They included the personnel of the Research and Development Center at Avery Point, Connecticut, who provided LORAN C and HP9915 tracking equipment, and provided programs for data collection and reduction of this data to a format compatible with Ship Analytics systems. In particular, the data collection team would like to thank Lieutenant Douglas Taggart who offered continual, unstinting assistance with both equipment and programming needs.

We are grateful for the cooperation of the Coast Guard First District in consulting with us and in changing the aid arrangements for the project We want to thank individually Captain David Parr from that district.

We want to name and thank Coast Guard representatives from Headquarters who worked with us. Commander Donald Murphy and Lieutenant H.H. Sharpe from the Office of Navigation were very central. From the Office of Research and Development Commander Robert Bates and Lieutenant John Anthony, now Lieutenant Commander, began with us in 1983. Lieutenant Commander Anthony provided practical assistance in preparing for the collection of electronic data on Narragansett Bay. He was joined and then replaced by Lieutenant Wallace Ridley, who guided us to the end of the implementation process and the preparation of this report. And we are grateful to Mr. Karl Schroeder of the Officer of Research and Development for providing continuity for us

back to the beginning of the implementation effort and the beginning of the project.

Even more than the Aids to Navigation project as a whole, the implementation task was the effort of a very extended group.

EXECUTIVE SUMMARY

INTRODUCTION

The research reported here is a part of the United States Coast Guard's Performance of Aids to Navigation (AN) Systems Project. The objective of this project is to provide guidelines for the evaluation and design of AN systems in restricted waterways. The major effort in this project has been the evaluation of aid systems under a variety of conditions on a marine simulator developed for the project at Ship Analytics, Inc., North Stonington, Connecticut. Performance data available at an interim point in 1982 was used to develop the "Draft SRA/RA Systems Design Manual for Restricted Waterways." Components of the project since then include additional simulator experiments, a validation of the simulator, and a test implementation at sea. A revision of the manual, benefiting from these later components, is planned for the spring of 1985.

This report describes the Implementation of the draft manual at sea. Implementation tested the recommendations contained in the manual by applying them to an actual waterway where the markings did not conform to the manual's simulator-based research findings, making changes in the aid markings and evaluating the contribution the changes made in shiphandling performance and safety. Inherent in this process was a larger objective: to develop the methodology to achieve this implementation of the manual's recommendations.

RISK ASSESSMENT AND RISK MANAGEMENT

Before aids can be put in place or changed in a particular waterway, the effect of the aids on piloted performance must be evaluated. The AN project has aimed to define a quantifiable, objective method for measuring aids' effectiveness through simulator experiments and the manual. The methodology defined in the manual sets an objective basis to support decisionmaking. This basis is risk assessment. The actual decisionmaking is risk management, and is a subjective process. It is judgmental since it adds local concerns and fiscal considerations to assessed risk in the decisionmaking equation.

The decision in the risk management process may be based on aid effectiveness, efficiency or economy. Effectiveness maximizes piloted performance, thus minimizing risk, for a given arrangement under given conditions. Economy emphasizes the cost of the arrangement. Efficiency balances effectiveness with economy: the greatest effectiveness for the lowest cost or least number of aids. The implementation task proved the decisionmaking process on channel markings may vary widely depending on the emphasis of the "risk manager." It pointed the way, however, to the implementation methodology, a sequential process the manager should follow in placing or altering aid arrangements for given waterways.

THE EXPERIMENT

As initially designed, the Implementation task focused on remarking two areas in Narragansett Bay, Rhode Island, one chosen for more effective marking (lighting an unlighted turn buoy), one for more economical marking (reducing the number of buoys in a reach). Via the simulator experiment, performance in alternative aid arrangements was examined in each area and compared to performance in the areas as originally marked. Concomitantly ship track data was also collected at sea on Narragansett Bay transits for comparison with track performance once the aids were actually changed on the bay.

The simulator experiment showed improved performance in the turn that was lighted for more effective marking. The alternatives in the reach examined in the economy move showed little change in performance. A Coast Guard review of these latter results led to their suggestion for an entirely new, even more economical, alternative marking in this reach. It was an alternative that also followed the dictates of the draft manual pointing to the conclusion that the manual and simulation were complementary, but neither all-inclusive methods for implementing aid changes in a waterway.

THE RISK MANAGEMENT PROCESS

The risk management task became more complicated when the Coast Guard announced the decision to actually change the configuration of the buoys based on their alternative design. Some pilots and organizations connected with use of the bay objected to the removal of several of the designated buoys. Their knowledge of local conditions, particular piloting hazards, concerns and preferences, added an additional factor to the implementation process. This local input led to the final implementation configurations. It was based on efficiency rather than solely economy or effectiveness. It balanced the costs of potential accidents with the costs of buoys alone, regardless of whether they were unlighted, or the more expensive lighted buoys. This was another step in the evolution of a risk management process.

AT-SEA IMPLEMENTATION

The final aid changes were:

- the originally proposed addition of a lighted turn buoy in a three-buoy turn
- replacement of three gates (two unlighted, one lighted) with two lighted gates in one 2.2 nm reach
- placing a lighted buoy at the apex of a turn to replace an unlighted one after the turn

The results of the track plots taken of at-sea transits after the aid changes included the following.

- Best results at night occur when three unlighted buoys mark turn cutoffs of critical turns. These include large angle turns or turns without natural aids or background cultural lights.
- Pilots use the cutoff turn in the day regardless of how it is marked, but make full use of a cutoff at night only if it is clearly marked.
- Performance in the straight legs is not affected by gated buoy spacing. In a turn, however, if there is no pullout buoy, the first gated buoys should be placed near the turn.

CONCLUSIONS

The results of the at-sea implementation verified the recommendations of the draft manual. That the recommendations are verifiable at sea supports the conclusion that the manual and the basic assumptions built into it are sound. A major benefit of the Implementation task is confidence in the draft manual -- and the final design manual.

Experience with the draft manual suggested changes to be made in the final design manual.

- The final design manual will be more flexible and will enable the user to adapt the guidelines to unique conditions.
- The final design manual will be less conservative and more accepting of a variety of channel markings.

RECOMMENDATIONS

This evolving Implementation task process spotlighted the difference between risk assessment and risk management. The recommendations and procedures in the draft manual, based on simulator experiments, provide the basis for risk assessment. Based on the assessment, the process of risk management must select the criteria for placing or changing an aid system -- economy, effectiveness, or, most likely, efficiency -- and balance that with specific local conditions and user concerns. These risk management issues must be addressed early in any implementation process. Based on the experience of this task, the following order of steps is recommended:

1. Selection of Coast Guard criteria for risk management
2. Consideration of local conditions and pilots' preferences
3. Manual design and evaluation of alternatives
4. Consideration of trade-offs among all factors
5. Simulator evaluation for difficult choices (optional)
6. Change in aid system

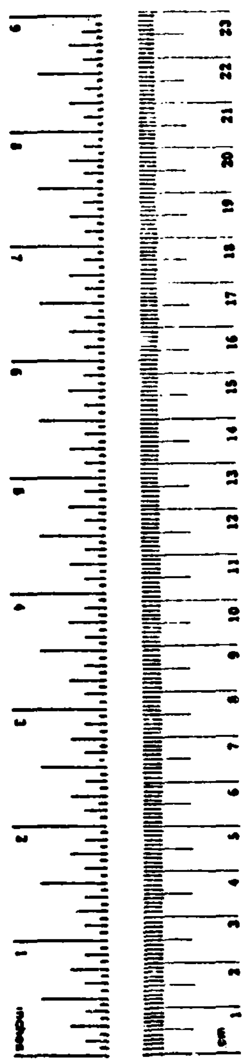
Post-change evaluation may also be necessary to test aid effectiveness and user acceptance. The final conclusion is that this is a fluid process, in which real world concerns and manual recommendations must be balanced and interpreted flexibly.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

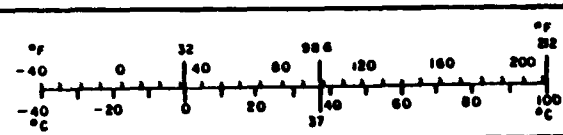
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Section 1
INTRODUCTION

1.1 PROJECT OVERVIEW

The research reported here is part of the United States Coast Guard's performance of Aids to Navigation (AN) Systems Project. The objective of this project is to prepare a decisionmaking tool for the design and evaluation of aids to navigation systems in restricted waterways. This tool is in the form of a manual that provides guidelines for evaluating aids to navigation systems. To provide quantitative data for the design process, the major effort in the project has been simulator evaluation of aids to navigation systems under a variety of channel, ship, and environmental conditions. The evaluations included fixed and floating visual aids, radio aids (Loran C), and radar. These simulator evaluations are generic with no specific waterway modeled. Rather than modeling an actual waterway, variables affecting navigation in restricted waterways were identified[1] and evaluated systematically by nine aids to navigation simulation experiments. The variables impacting the navigation process were: (1) ship variables including perspective view, speed, size, and maneuverability; (2) channel configuration including banks, width/depth, turn angle, and type of turn; (3) environmental factors including current/wind, day/night, visibility/detection range, and traffic; and (4) aid to navigation placement including spacing, flash period, turnmarking, and straight channel marking. Each experiment focused on a different combination of variables which interact with one another.

Performance evaluation of data collected by generic experiments consisted of calculating the crosstrack mean and standard deviation of the group of ship transits at specified intervals. This data was statistically tested by F-tests and t-tests to compare performance to identify differences. The data was analyzed to evaluate the aid system and performance precision to determine the system effectiveness.

In addition to generic data, at-sea and simulator data pertaining to specific waterways were also collected. One purpose was to validate the simulator by comparing performance on the simulator to that found at sea to evaluate the simulator and its ability to represent at-sea conditions. Results of this study are presented in the Validation Report.[2] A second purpose was to implement changes to the buoy arrangement of a real channel, both on the simulator and at sea, to evaluate the effect of the changes. The changes were recommended by the draft manual. Results of this study are presented in this report.

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[1]W.R. Bertsche and R.C. Cook. "Analysis of Visual Navigation Variables and Interactions." U.S.Coast Guard, Washington, D.C., October 1979.

[2]M.W. Smith, K.L. Marino, J. Multer, and J.D. Moynehan. "Aids to Navigation Principal Findings Report: Validation for a Simulator-Based Design Project." CG-D-06-84, U.S. Coast Guard, Washington, D.C., July 1984.

The Aids to Navigation Systems Project is ongoing, so at an interim point the available generic data were used to develop the "Draft SRA/RA Manual for Restricted Waterways"[3]. The purpose of the manual was to provide quantitative data for decisionmaking in the design and maintenance of aid systems. Data collected after the draft manual, including that from the Validation and Implementation tasks, are designed to extend the domain of the revised manual. A revision of the manual benefiting from the new data and the experience with the draft manual is planned for the spring of 1985.

1.2 ROLE OF THE IMPLEMENTATION TASK

A major objective of the Implementation task is to develop methodology to achieve implementation of findings in the short range aids to navigation research area. Part of this process was to: (1) identify aids to navigation design and placement problems existing in a real world setting; (2) make improvements based on the draft manual recommendations, pilot preferences, and local conditions; and (3) evaluate the impact of these changes on performance.

The Upper Narragansett Bay was selected as the real waterway to implement aid changes recommended by the draft manual because: (1) it was a buoyed channel with some markings that did not adhere to the draft manual recommendations; (2) 30,000 dwt midship bridge tankers, the same type of ship modeled in simulator experiments, made up a substantial portion of bay traffic; (3) it was close to Ship Analytics so ship transits were accessible; and (4) there was a working relationship with pilots from Northeast Marine Pilots, Inc.[4,5]

In evaluating various aid arrangement alternatives for the Upper Narragansett Bay, information was obtained in several steps from several sources. First at-sea data was collected in the originally marked Narragansett Bay. At the same time, a simulator experiment, which modeled both the original and alternative Narragansett Bay aid arrangements, was conducted. The alternative aid arrangements were designed for economy and efficiency. This data was evaluated to assess performance quantitatively. The Coast Guard evaluated this data and made recommendations for at-sea implementation. These recommendations were reviewed by representatives of the local pilots association. All these factors were then reconsidered by the Coast Guard and new recommendations were formulated.

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[3]W.R. Bertsche, M.W. Smith, K.L. Marino and R.B. Cooper. "Draft SRA/RA Systems Manual for Restricted Waterways." CG-D-77-81, U.S. Coast Guard, Washington, D.C., February 1982. NTIS AD-A113236.

[4]J.W. Gynther and R.B. Cooper. "At-Sea Data Collection Plan for Prototype Implementation of Aid System Design Guidelines." U.S. Coast Guard, Washington, D.C., April 1982.

[5]J.W. Gynther and G.E. Grant. "Experimental Procedures for Prototype Implementation of Aid System Design Guidelines." U.S. Coast Guard, Washington, D.C., July 1982.

1.3 RISK ASSESSMENT AND RISK MANAGEMENT

The AN project has developed a quantifiable, objective method for assessing the risk of accident for ships transiting channels under varying aid configurations. This structured approach to risk assessment such as that identified in the draft manual assists the AN system designer to make objective decisions. In the manual, risk is measured by the relative risk factor (RRF) to determine the relative probability that for a given condition, such as ship size or visibility, and for a given AN system, such as number of buoys in a turn, there will be a grounding. Hence, the determination of risk as measured by the RRF can be accomplished objectively, based strictly on comparative relative probabilities.

Risk management, however, is essentially a subjective process. It is more judgmental and includes balancing local considerations with the assessed risk. It is also driven by considerations of resources required versus resources available. Within these limits, the draft manual provides that aid systems can be designed for effectiveness, efficiency or economy. The risk management process must weigh these criteria in the light of local considerations. Efficiency is the precision of performance to be expected from a given arrangement under given conditions. Central to the project is the assumption that this precision of performance is related to risk and safety. Economy emphasizes the cost of aid arrangements, aiming at the lowest cost. Efficiency is the greatest effectiveness for the smallest number of buoys or other aids, in other words, the lowest cost. Depending on which of these criteria is emphasized, different users of the draft manual may have different recommendations. In this implementation task designed to experimentally test the manual, the risk management process was clarified.

The effectiveness, economy, and efficiency criteria to design and evaluate aid systems can be applied in four ways. These include: (1) implementing the design manual, (2) simulating the waterway, (3) dialogue with local pilot associations, and (4) modifying the actual waterway. These procedures can be used jointly or independently. In the Implementation task each of these steps was used to evaluate and modify the Upper Narragansett Bay.

1.4 ORGANIZATION OF THIS REPORT

This report reviews the implementation process. Section 2 discusses the role of simulation as an evaluative tool in port design. Section 3 discusses the factors not considered in simulation, such as environmental and political issues. Section 4 discusses the at-sea implementation process as a test of the manual. The latter includes the rationale for the aid changes, predictions of performance, and discussions of performance. Section 5 sums up this report by describing general conclusions. This report also contains five appendices. Appendix A summarizes pilot opinions on the new channel markings. Appendix B provides track plots of simulator data of Narragansett Bay. Appendix C explains the derivation and calculation of the relative risk factor. Appendix D contains at-sea track plots of performance in the originally marked Narragansett Bay, and Appendix E contains at-sea track plots of performance in the modified channel.

Section 2

ROLE OF SIMULATION IN IMPLEMENTATION TASK

2.1 SIMULATION AS A TEST OF THE MANUAL'S PREDICTIONS

The role of simulation in the Implementation task was to demonstrate the application of the draft manual to an actual waterway in order to evaluate the AN system design process thus far developed in the project and to provide direction for future research. The "problem areas" chosen for application of the manual, as outlined in the Prototype Implementation Report,[6] were in the Popasquash Point Turn and Rumstick Neck Reach portions of Narragansett Bay. Two alternative markings were designed for each region. In Popasquash Point Turn, the simulated alternatives were a lighted two-buoy turn or a lighted three-buoy turn. In Rumstick Neck Reach three long-spaced staggered buoys marked the channel with two buoys on the right/one on the left in one scenario and two buoys to the left/one on the right in the other scenario. As outlined in the Prototype Implementation Report, altering Popasquash Point Turn was considered an "effectiveness" change because it provides more information than the original unlighted Buoy "4". In Rumstick Neck Reach, replacing the high density marking (three sets of gates) with staggered buoys was considered an "efficiency" change because it provides comparable information with fewer buoys.

The simulation experiment consisted of seven scenarios; two Narragansett Bay scenarios which reflected the original channel markings, four implementation scenarios which tested alternative aid arrangements to mark the channel, and one design condition scenario which evaluated the effect of wind and current on performance. This section emphasizes implications of the implementation scenarios; for other analyses and details see the Validation Report,[7] and the Preliminary Observations and Data Analysis Report.[8]

2.2 PERFORMANCE IN POPASQUASH POINT TURN

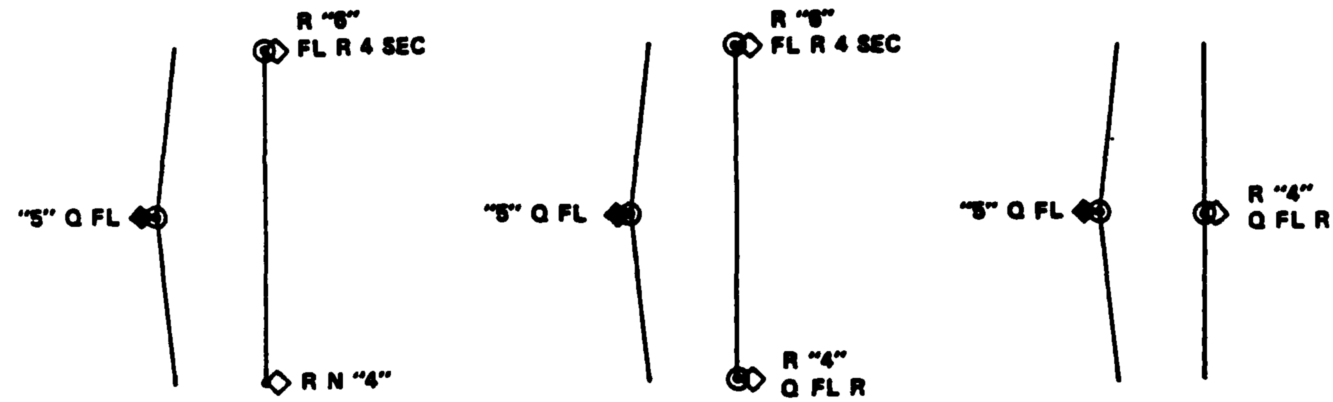
In Popasquash Point, nighttime performance was evaluated in the originally marked channel and in two alternatively marked channels. The original marking (Scenario 6) consisted of a three-buoy turn in the day and a two-buoy turn at night (the turn initiation buoy was unlighted while the turn apex and pullout buoys were lighted). One alternative was to modify this arrangement by lighting turn initiation Buoy "4" (Scenario 3). The second alternative was a two-buoy gated turn that was evaluated by Scenario 7. These are as shown in the following figures.

---

[6]Gynther and Cooper, op. cit.

[7]Smith, Marino, Multer, Moynehan, op. cit.

[8]G. Grant and J. Moynehan. "Aids to Navigation Validation II/ Implementation: Preliminary Observations and Data Analysis." U.S. Coast Guard, Washington, D.C., October 1979.



ORIGINAL MARKING SCENARIO 6 | THREE BUOY TURN SCENARIO 3 | TWO BUOY TURN SCENARIO 7

Performance in the alternatively marked channels was compared to that in the original channel. The comparison plots are in Appendix B. As indicated by Table 1, in the Lower Entrance the means of Scenarios 6 and 3 are approximately the same but the standard deviation is larger in Scenario 6. This is due to pilot's conservative turn strategies to avoid the unlighted buoy in the original channel. The conservative strategies are also reflected in a smaller mean and standard deviation in the Upper Entrance during recovery from the turn. Lighting Buoy "4" in Scenario 3 provides cues for turn initiation. Piloting strategies are more varied and some pilots use more of the channel and steer to the inside of the turn resulting in a higher mean and standard deviation in the Upper Entrance.

The data from the two-buoy gated turn (Scenario 7) indicate that performance is poorest with this configuration, presumably because pilots have no distance cues to determine the turn initiation point. Data from Table 1 show that in the Lower Entrance, the mean is closest to the centerline but the standard deviation is the highest, although this is not statistically significant at the 0.10 level. In the Upper Entrance, however, performance worsens as pilots deal with the consequences of beginning the turn late. Table 1 shows the mean and standard deviation is more than double that of other scenarios in the Upper Entrance. Also without a recovery buoy, recovery from the turn takes longer. The recovery buoy in the other scenarios keeps the track envelope within channel boundaries. Therefore, with the two-buoy configuration recovery takes twice as long (0.4 nm compared to 0.7 nm) as before.

2.3 PERFORMANCE IN RUMSTICK NECK REACH

In Rumstick Neck Reach, the original gated channel marking was compared to two staggered buoy configurations. One configuration had two buoys marking the left of the channel with one buoy on the right and the other

TABLE 1. SIMULATION EXPERIMENT: PERFORMANCE IN POPASQUASH POINT AT NIGHT

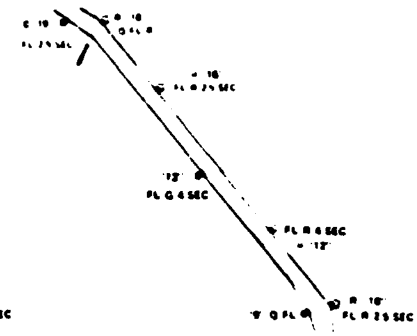
	Scenario 6 Original Marking		Scenario 3 Three-Buoy Turn		Scenario 7 Two-Buoy Turn	
Region	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Lower Entrance						
Before apex						
2375 feet	24R	50	20R	25	10R	49
1425 feet	25R	57	37R	43	27R	64
Upper Entrance						
After Apex						
1425 feet	71R	55	114R*	112	208R*	133*
2375 feet	56R	44	86R*	112*	179R*	119*

*Indicates performance with modified channel marking is statistically difference at $p<0.10$ when compared to performance with original marking.

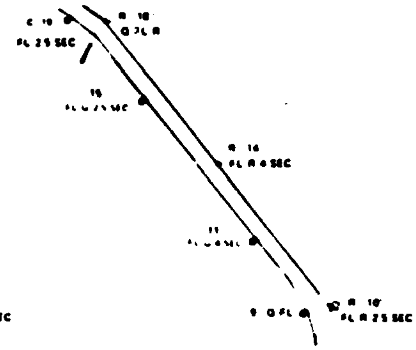
Means and standard deviations are in feet from the centerline of the channel.

configuration had one buoy marking on the left and two buoys on the right. These are shown below.

ORIGINAL MARKING
SCENARIO 6



STAGGERED BUOYS
1 INSIDE, 2 OUTSIDE
SCENARIO 7



STAGGERED BUOYS
2 INSIDE, 1 OUTSIDE
SCENARIO 3

Performance with each configuration was compared in the day and at night to that of the original marking. For daytime, there were no statistical differences in performance as shown in Table 2. This may be due to the lack of design conditions, the wind and current that were part of the generic scenarios. (For discussion of the design conditions and their effects on performance see previous reports.[9,10]) In a straight segment such as Rumstick Neck Reach, where there is no traffic or adverse environmental conditions, the performance is not sensitive to aid arrangements, thus there are no differences.

At night the original marking (Scenario 6) was one lighted set of gates located midway in the channel. Performance was best with this configuration as indicated in Table 2. The two staggered arrangements also resulted in satisfactory nighttime performance. When comparing performance with the arrangements, there were differences between the standard deviations. Performance is worst when the staggered buoys are to the inside (two buoys to the left and one to the right). The standard deviation is very high (between 80 and 100 feet) through most of the leg. The high standard deviation initially results from a lack of pullout buoy onto Rumstick Neck Reach. The track spread remains high because the tracks never settle out. The other staggered scenarios result in better performance because there are two buoys marking the right side of the channel that provide a boundary on the side of the channel that they would be on if there were traffic.

2.4 SUMMARY AND CONCLUSIONS

Simulation is one alternative to evaluate the effects of potential navigational aid changes. In the implementation simulation experiment,

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[9] Ibid.

[10] Smith, Marino, Multer, Moynehan, op. cit.

TABLE 2. SIMULATION EXPERIMENT: PERFORMANCE IN RUMSTICK NECK REACH

DAY

	Scenario 5		Scenario 4		Scenario 8	
	Original Marking		Staggered Buoys 2 Left, 1 Right		Staggered Buoys 1 Left, 2 Right	
Along Channel Distance	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
0.3 nm	20R	44	40R	57	10R	57
0.6 nm	31R	47	54R	52	32R	53
1.0 nm	16R	49	45R	46	24R	46
1.5 nm	4L	48	33R	46	2L	46

NIGHT

	Scenario 6		Scenario 3		Scenario 7	
	Original Marking		Staggered Buoys 2 Left, 1 Right		Staggered Buoys 1 Left, 2 Right	
Along Channel Distance	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
0.3 nm	69	70	73	118	5	75
0.6 nm	69	59	74	104	17	65
1.5 nm	53	39	60	82*	53	60
1.5 nm	19	29	29	81*	19	60*

*Indicates performance with modified channel marking is statistically different at $p < 0.10$ when compared to performance with original marking.

Means and standard deviations are in feet from centerline.

several alternative arrangements were evaluated. Some conclusions can be drawn from the data, and these are summarized by Table 3. Table 3 measures the effectiveness of the aid arrangements that were evaluated in the implementation simulation by comparing relative risk factors. Here relative risk measures the relative probability that for given aid arrangements there will be a grounding. The derivation and calculation of this measure are described in Appendix C.

TABLE 3. EFFECTIVENESS INDICATED BY THE RELATIVE RISK FACTOR* IN IMPLEMENTATION SIMULATION

	Popasquash Point Turn - Turn Initiation		
	Original Marking	Buoy 4 Lighted	2 Buoy Gated Turn
Night	0.0029	0.0003	0.0078
	Rumstick Neck Reach - At Midpoint in Leg		
	Gated Original	Staggered 2 left/1 right	Staggered 2 right/1 left
Day	0.0001	0.0005	0.0001
Night	0.0001	0.0504	0.0089

*The Relative Risk Factor as a measure is described in Appendix C.

In Popasquash Turn, performance was evaluated only at night. Lighting Buoy "4" offers pilots the best turn information. When the buoy is not lighted, it is more an obstacle to avoid rather than an aid. The gated two buoy turn resulted in the worst performance because it did not provide adequate information as to when to begin the turn.

In Rumstick Neck Reach under daytime conditions, without the difficulties of design conditions, traffic or night, performance did not differ among aid arrangements. Since the two alternatives compared in Rumstick Neck Reach were the most extreme (short-spaced gates and long-spaced staggered) and showed no differences in the daytime, it is unlikely that simulation would have discriminated among other arrangements. The nighttime simulation showed some differences but these were not large nor were they logical (staggered risk is lower than gated) because of continued effects of the better marking for turn pullout. It is unlikely that nighttime evaluation of the four alternatives would have shown useful differences between markings because of the lack of difficulties. Without the stress of "design conditions", the implementation simulation showed only grossest differences among aid arrangements such as the differences in the turn pullout onto Rumstick Neck Reach and the differences through the Popasquash Point Turn. Because these differences appear even without the design conditions, they identify worthwhile changes.

The manual and simulation are alternative but complementary methods of evaluating aid system effectiveness. The implementation simulation, as an alternative way of evaluating effectiveness did not include all the alternatives later considered. These alternatives are discussed in the following sections.

Section 3

FURTHER CONSIDERATIONS BEFORE AID CHANGES

3.1 ALTERNATIVES FOR IMPLEMENTATION

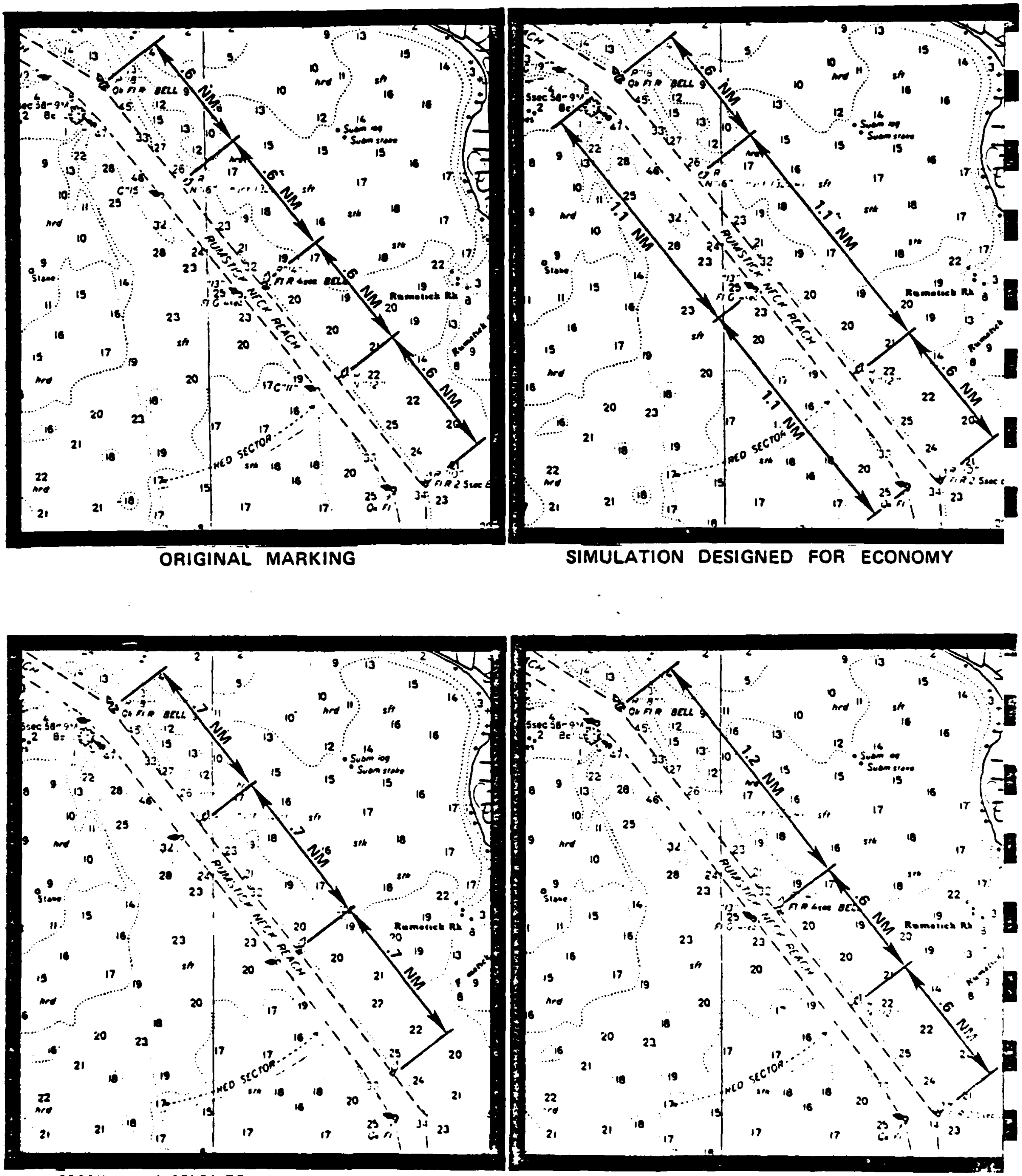
In the implementation of aid systems in the Narragansett Bay, information was collected from five sources: (1) at sea in the originally marked channel, (2) on the simulator where alternative aid arrangements were designed for efficiency and economy, (3) by the draft manual memo[11] which designed alternative arrangements for effectiveness, (4) by input from the local pilots association, (5) by Coast Guard NSR review and design based on informal cost/benefit (tradeoff) analyses. The data from the original aid arrangement were used as a baseline to evaluate the alternative aid arrangements. The data from the simulation and from the draft manual are numeric and provide assessments of risk. These data result from application of the draft manual to design for effectiveness, efficiency, and/or economy. The information from the pilots association represents political input and provides the "local knowledge" that is unattainable by reviewing charts. It identifies piloting hazards, concerns, and preferences. Basically, pilots want aid system effectiveness; they expect the greatest amount of information possible from the aid system. The Coast Guard's role in this process is to identify and manage risk. The aid system is designed to reduce the risk of grounding.

In reviewing the Narragansett Bay original aid configuration, it was determined that aid improvements could be made in Popasquash Point Turn and Rumstick Neck Reach (including Conimicut Point Turn). The improvement to Popasquash Turn was to replace an unlighted buoy with a lighted one. This marked the 15-degree turn with three buoys at day and night. It results from unanimous recommendations of the draft manual, the pilots, and the Coast Guard. The design of Rumstick Neck Reach was more controversial. Four alternative arrangements were considered for this reach. These include: (1) the original arrangement, (2) the staggered arrangement from the simulation experiment, (3) the Coast Guard NSR recommendation, and (4) a draft manual recommendation found in the Ship Analytics' memorandum to the Coast Guard. These arrangements are illustrated by Figure 1.

As explained in Section 2, aid arrangements can be specifically designed for: (1) effectiveness to provide maximum precision of performance, (2) efficiency to provide the greatest effectiveness for the smallest number of buoys or other aids, or (3) economy for low cost. The effectiveness, efficiency, and economy criteria were used to compare these arrangements. The assessment of these alternatives are summarized by Table 4.

In the comparison for effectiveness, the manual recommendation ranked highest. This is not surprising since the criterion used to generate the arrangement were also used to evaluate it. The Coast Guard NSR arrangement and the original arrangement ranked intermediate in effectiveness because

[11] M. Smith. Memorandum to LT W. Ridley. "Air Arrangments in Rumstick Neck Reach, Selection criteria, and the AN Design Manual." August 22, 1983.



ORIGINAL MARKING

SIMULATION DESIGNED FOR ECONOMY

MANUAL DESIGNED FOR EFFECTIVENESS

COAST GUARD NSR

Figure 1. Alternatives for Implementation - Rumstick Neck Reach

TABLE 4. ASSESSMENT OF ALTERNATIVES FOR RUMSTICK NECK REACH

1. Present Arrangement	2. Simulation Experiment	3. Coast Guard NSR Recommendation	4. Manual guidelines for maximum effectiveness
TURN UPBOUND, 35 degrees, noncutoff			
two buoys day: RRF = 0.0035 two buoys night: RRF = 0.0110	two buoys day: RRF = 0.0035 two buoys night: RRF = 0.0110	two buoys day: RRF = 0.0035 two buoys night: RRF = 0.0110	three buoys day: RRF = 0.0000 three buoys night: RRF = 0.0012
REACH			
day: 0.6 nm to first gate? guidelines: yes night: 1.2 nm to first gate? guidelines: no	day: 0.6 nm to first stag. buoy? guidelines: no night: 0.6 nm to first stag. buoy? guidelines: no	day: 0.6 nm to first stag. buoy? guidelines: no night: 1.2 nm to first gate? guidelines: no	day: 0.7 nm to first gate? guidelines: yes night: 0.7 nm to first gate? guidelines: yes
day: 0.6 nm gates in reach? guidelines: yes RRF: 0.0000	day: 1.1 nm to stag. in reach? guidelines: no RRF = 0.0050	day: 1.2 nm to gates in reach? guidelines: yes RRF = 0.0000	day: 0.7 nm gates in reach? guidelines: yes RRF = 0.0000
night: 1.2 nm gates in reach? guidelines: yes RRF = 0.0000	night: 1.1 nm to stag. in reach? guidelines: no RRF = 0.0050	night: 1.7 nm spacing in reach? guidelines: yes RRF = 0.0000	night: 0.7 nm gates in reach? guidelines: yes RRF = 0.0000
TURN DOWNBOUND, 18 degrees, noncutoff			
Light off edge inside, buoy outside? guidelines: no no applicable RRF	Light off edge inside, buoy outside? guidelines: no no applicable RRF	Two-buoy gate? RRF between one buoy and three buoys day: 0.0000 0.0000 night: 0.0800 0.0105	Two-buoy gate? RRF between one buoy and three buoys day: 0.0000 0.0000 night: 0.0800 0.0105

1. The relative risk factor values for the turns were taken from the turn design memos of September and October 1982.
2. The relative risk factor values for the reaches were taken from the RRF plots of January 1983.
3. These relative risk factors were not adjusted for channel width, ship size, or ship speed.

trade-offs with other criteria were built into their design. The simulated staggered arrangement was least effective because efficiency, or low buoy number, was the major design consideration. The original arrangement and the staggered arrangement were evaluated in the simulation experiment and discussed in Section 2 of this report.

After ranking the arrangements in order of effectiveness, the number of buoys each required were compared to evaluate aid efficiency. Using the buoy counts summarized in Table 5, the arrangements can be ranked from least to most buoys. The most efficient arrangement is either the staggered arrangement from the simulation experiment or the Coast Guard NSR arrangement with both using 7 buoys. The manual design ranked next in efficiency using 9 buoys. The original arrangement did not rank high in efficiency because it used 10 buoys to mark the channel.

The buoy count summarized in Table 5 can be used to estimate the economy of the arrangement, using a 1 to 7 cost ratio of lighted to unlighted buoys. In relative economy, the alternatives ranked as follows. The Coast Guard NSR arrangement was the most economical with 43 units closely followed by the original arrangement with 46 units and the staggered arrangements from the simulated experiment with 49 units. The manual recommendation was by far the most expensive requiring 63 units. However, the selection is a risk management matter and should not be made on the cost of aids alone.

A summary of the alternatives ranked by effectiveness, efficiency, and economy is listed by Table 6. These arrangements exist because each was designed to meet different criteria. By shifting weights among criteria, some alternatives can be eliminated and new alternatives can be added.

This table shows the original arrangement is lowest on efficiency, and it also scored low in the other criteria. Therefore, it may not be the best option. The simulation arrangement was designed with heavy emphasis on efficiency. If there is no reason to give efficiency such heavy emphasis, the simulation arrangement may also be eliminated. The Coast Guard NSR alternative was designed to trade-off among these criteria. It is high in efficiency and economy and only the manual alternative is higher in effectiveness. The manual alternative has the highest effectiveness, but it is the least economical, if only the cost of the aids is considered. The viability of this alternative depends on the level of effectiveness that is considered necessary. If the highest effectiveness is necessary, then only the manual recommendation will suffice. It has been suggested that an aid system with an established record of safety be used as a threshold for acceptable risk. Since the original aid arrangement had an acceptable level of safety, there is no reason to go to a more effective arrangement so the manual recommendation can be eliminated. Therefore, the Coast Guard NSR recommendation was selected as the best option for implementation.

This arrangement, however, was not used as the implementation arrangement because other factors, specifically that of pilots' association input, were not considered. What became apparent in the implementation process was that local conditions needed to be considered early. The pilots and any other local agencies having jurisdiction over use of the waterway should have been more involved, both for the knowledge they provide and to maximize their

TABLE 5. NUMBER OF BUOYS AND ASSOCIATED COSTS IN UNITS

1. Original

6	lighted*	x	7	=	42	units
4	unlighted	x	1	=	4	units
10	buoys				46	units

2. Simulation

7	lighted*	x	7	=	49	units
7	buoys				49	units

3. Coast Guard NSR

6	lighted	x	7	=	42	units
1	unlighted	x	1	=	1	unit
7	buoys				43	units

4. Manual

9	lighted	x	7	=	63	units
9	buoys				63	units

*Conimicut Point light is counted as a lighted buoy to simplify the discussion.

TABLE 6. RUMSTICK NECK REACH ALTERNATIVES RANKED BY CRITERION

Ranking	Effectiveness	Efficiency	Economy
1	Manual	Simulation Coast Guard NSR	Coast Guard NSR
2	Coast Guard NSR	--	Original
3	Original	Manual	Simulation
4	Simulation	Original	Manual

cooperation. One of the objectives of the Implementation task was to develop the methodology for implementation of existing channel evaluation and possible redesign. The following subsections identify other factors to be considered and the methodology recommended for the implementation process.

3.2 FACTORS NOT CONSIDERED BY THE ALTERNATIVE AID ARRANGEMENTS

In designing alternative aid arrangements for the Narragansett Bay, the waterway was simplified to apply recommendations of the draft manual. The factors considered included the aids to navigation and the waterway configuration, specifically channel width, channel depth, length of leg, turn angle, and type of turn (cutoff or noncutoff). Other factors need to be considered in the analysis of aid system design. Some of these are listed below, but the list is not inclusive. Since the manual will be implemented in other waterways, this list of factors was developed after reviewing a variety of waterways, including the Narragansett Bay. Since these factors are unique to each waterway, the ultimate judgments and decisions regarding aids to navigation system design must rest with individual Coast Guard managers, particularly on the local level.

- Channel surroundings. Natural aids such as church steeples and background cultural lights.
- Traffic. Types of ships using the channel and the nature of the cargo, traffic density, and local traffic regulations.
- Weather. Frequency, intensity, and duration of winds, ice, thunderstorms, and fog.
- Ecology of Waterway. Including tides, currents, bottom type, bank effects, and waterway uses.
- Population Identification. Population density and population attitudes.
- Pilot Association. Local pilot association's knowledge of the waterway and resulting needs and preferences.

Specific conditions within these categories for the Narragansett Bay are summarized in Table 7. The most important factor in this list is the input from the local pilots association. The pilots are key users of the waterway so their preferences and opinions result from intimate familiarity with the

TABLE 7. FACTORS NOT CONSIDERED EARLY IN THE IMPLEMENTATION PROCESS

CHANNEL SURROUNDINGS

- Natural aids and background cultural lights present no problem. Many cultural lights are used as aids.

TRAFFIC

- Commercial traffic is generally light with ships under 40,000 dwt. This traffic consists of car carriers, bulkers, tankers, and barges with tugs.
- Since traffic is light and the channel is short, pilots can schedule where to meet oncoming ships. They prefer to meet in long straightaways such as Rumstick Neck Reach.
- There are no local traffic regulations.

WEATHER

- Winds average a speed of 10 knots. It is generally from the southwest except in the winter when it is from the northwest.
- Sometimes floating ice or packs of field ice cause problems.
- Fog causes visibility problems in lower bay. It is not a problem in channel legs analyzed here.

ECOLOGY OF WATERWAY

- Mean tides vary from 3.5 feet at the entrance of Narragansett Bay to 4.6 feet at Providence.
- Currents are weak and variable in the Providence River and Upper Narragansett Bay.
- The channel generally has a mud bottom although there are numerous rock ledges and outcroppings. Of particular concern to the pilots is the ledge off Rumstick and outcroppings off Conimicut Point.
- The waterway is used for commercial and recreational vessels. Also there is limited fishing and quahogging in the Bay.

LOCAL POPULATION IDENTIFICATION

- Local population density is moderate to heavy. There are small towns with residences on the shores surrounding the channel. Population increases as the channel approaches Providence.

PILOT ASSOCIATION OPINIONS AND PREFERENCES

- Background lighting is generally helpful. However, off Popasquash Point pilots need three buoys for the turn because of the lack of background lighting. In other areas of the channel, particularly Bullock Point Reach and north, natural aids are helpful.
- Rumstick Neck Reach is a critical part of the channel because of shoaling and because it is the preferred meeting traffic location due to upcoming S-shaped turn through Conimicut Point. Also at flood current, the ships have a tendency to be pushed to the right of the channel. Therefore, the pilots recommend gated buoys mark this leg.

waterway. Their input provides the "local knowledge" that is unattainable by reviewing charts. In the Narragansett Bay the pilots identified hazards that could be reduced through aid modification. These hazards were: (1) in Popasquash Point where a lack of background lighting required the turn to be well marked at both day and night, (2) in Rumstick Neck Reach which has shoals on both sides of the channel as well as a flood current that pushes ships to the right of the channel, and (3) in the Conimicut Point S-shaped turn (Conimicut Point Reach is only 0.8 nm and connects Rumstick Neck Reach, an 18-degree turn, to Bullock Point Reach, a 40-degree turn). Because of the sharp turn, Rumstick Neck Reach is the preferred location for meeting traffic. Some of these factors had not been considered earlier, so the Coast Guard NSR recommendation was modified and this arrangement was used in the at-sea implementation. The changes to the NSR arrangement were in Rumstick Neck Reach where gated lighted buoys were added and in Conimicut Point Reach where Buoy "19" was moved to the turn apex and lighted resulting in a two-buoy turn. This arrangement is shown by Figure 4 in Section 4 where pilot performance at sea with this arrangement is also discussed.

3.3 RECOMMENDATIONS FOR FUTURE IMPLEMENTATIONS

One of the objectives of the Implementation task was to develop methodology and supporting materials to achieve implementation of findings in the short range aids to navigation research area. Supporting materials are being developed by this project and will be released in the form of manual in 1985. The recommended implementation methodology is shown by Figure 2. It consists of six steps, one of which is optional. First the Coast Guard should consider the criteria for risk management. This can include an evaluation of the waterway in terms of effectiveness, efficiency, or economy. These criteria can be further analyzed to identify trade-offs. Next local conditions such as those identified in Section 3.2 need to be considered. A good source of this information comes from interviewing local users such as the pilots association. The manual can then be applied to design and evaluate alternative aid systems. All the information pertaining to aid system alternatives should then be reviewed by the Coast Guard. If the waterway conditions are difficult or unusual, several alternatives can then be tested by simulation. After further reevaluation, the improved system can be implemented in the waterway.

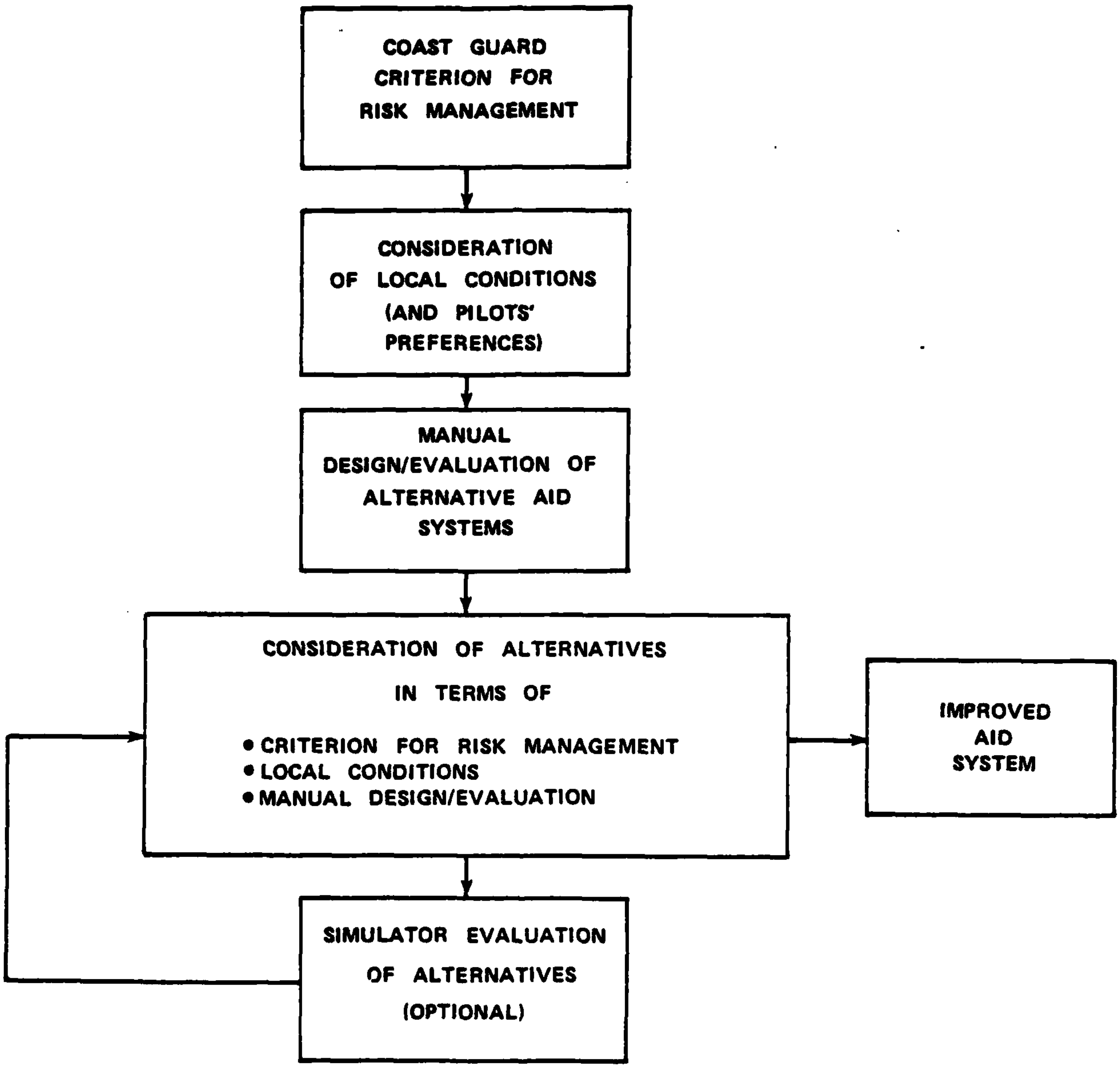


Figure 2. Methodology for the Implementation Process

Section 4

AT-SEA IMPLEMENTATION AS A TEST OF THE MANUAL

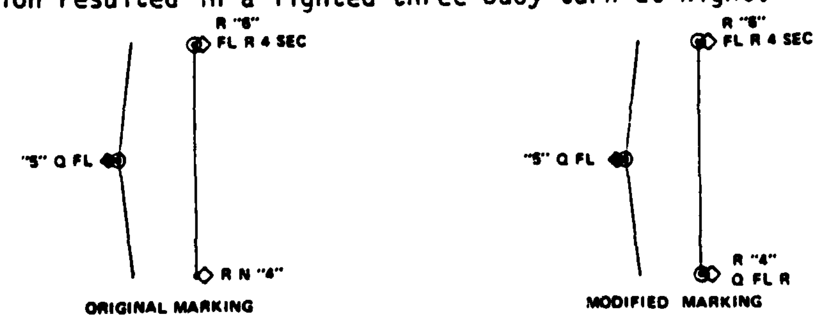
4.1 PREIMPLEMENTATION AND POSTIMPLEMENTATION DATA COLLECTION

Data was collected at sea in the Narragansett Bay twice. The first time, preimplementation, was in the originally marked channel shown by Figure 3. The second time, postimplementation, was in the modified channel shown by Figure 4. The channel was modified after aids to navigation design problems were identified and improvements were made based on draft manual recommendations, pilot preferences, local conditions, and other factors discussed in Section 3. Aid changes were made in Popasquash Turn, Rumstick Neck Reach, and Conimicut Point Turn. An evaluation of the effectiveness of these modifications is contained in the following subsections.

The at-sea data collection methodology was the same for both collections. In preimplementation eight ships were tracked: four in the daytime and four at night. In postimplementation four ships were tracked: two in the daytime and two at night. An Internav 404 Loran C receiver and an HP9915 computer for recording were supplied by the Coast Guard for data collection. The Coast Guard charted a waypoint survey to set reference points for the data collection and reduction. They established a station in Bristol, Rhode Island to continuously monitor the Loran C time differential (TD) signals to estimate the local distortion between Loran C grid position and actual geographic position. A data analysis program and facilities to use the program were provided at the Coast Guard's Research and Development Center in Groton, Connecticut. The data was further processed at Ship Analytics so that it could be analyzed and plotted like experimental data. For more details see the Validation Report[13] and the At-Sea Preimplementation Draft Principal Findings Report.[14]

4.2 PERFORMANCE IN THE MODIFIED POPASQUASH POINT TURN

The change made in Popasquash Point Turn was that unlighted Buoy "4" was replaced by a lighted buoy. The buoy location was not changed. This modification resulted in a lighted three-buoy turn at night.



[13] Smith, Marino, Multer, Moynehan, op. cit.

[14] J.D. Moynehan. "Aids to Navigation Implementation At-Sea Preimplementation Draft Principal Findings." U.S. Coast Guard, Washington, D.C., September 1983.

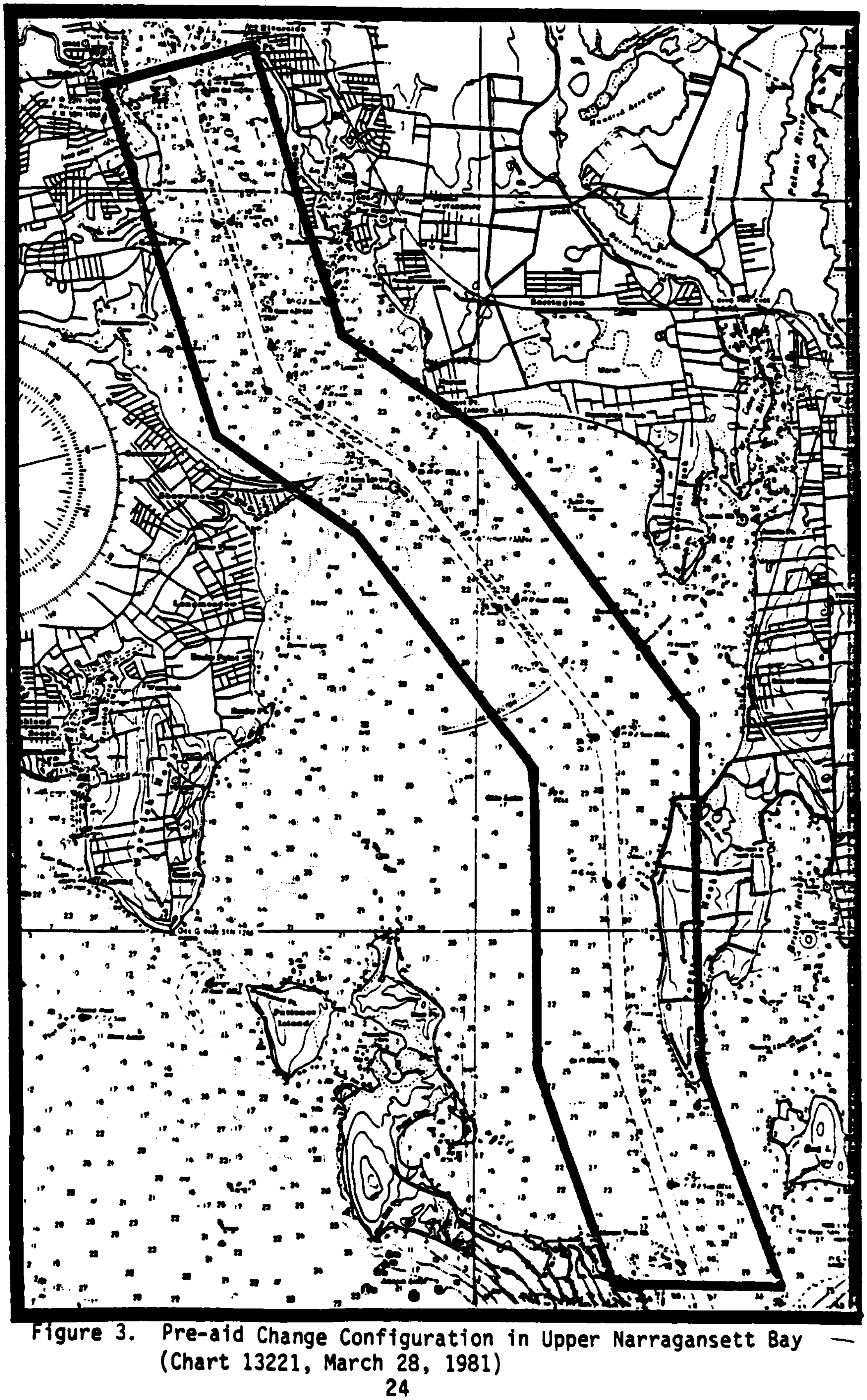


Figure 3. Pre-aid Change Configuration in Upper Narragansett Bay (Chart 13221, March 28, 1981)

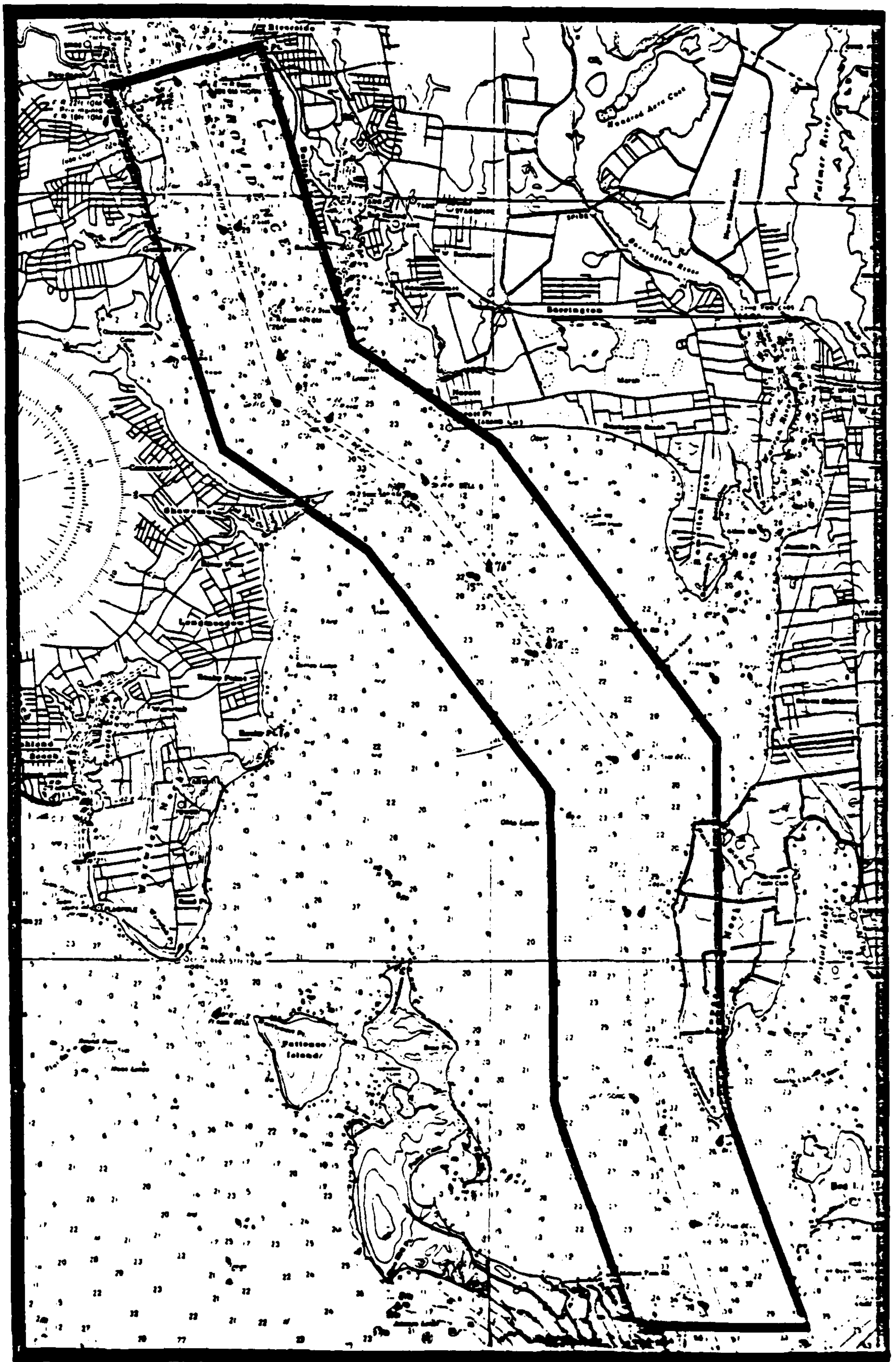


Figure 4. Modified Aid Configuration in Upper Narragansett Bay

The rationale for this modification was the 15-degree cutoff turn in the Entrance Channel is marked by three buoys, however, at night only two buoys are lighted. The draft manual indicates this is not a recommended nighttime configuration for a cutoff turn.

It was hypothesized that the additional lighted buoy would make performance during nighttime operations more similar to that in the day. The additional lighted buoy was not expected to change daytime performance.

Performance in Popasquash Point is summarized by Table 8. Combined mean and standard deviation track plots of at-sea data appear in Appendix D for the original channel and Appendix E for the modified channel. During daytime transits, the means are very similar, as would be expected, because three buoys marked the turn in both pre- and post-aid changes. The standard deviation, however, is higher in the turn (post-aid) and results from the same pilot doing very different things in different transits. The high standard deviation cannot be attributed to the change in aid.

By lighting the buoy, nighttime performance is more similar to day. The pilots make the turn more to the inside and the tracks are closer to the right (the side that the new buoy is on). When comparing pre- and post-aid change nighttime performance, it can be inferred that if a turn initiation buoy is available, uncertainty as to when to begin the turn is reduced. When the buoy is not lighted, pilots avoid it by moving away from it. This occurs in Lower Entrance pre-aid change with the mean further left and the standard deviation higher than when the buoy is lighted.

It can be concluded that pilots use the cutoff in the day regardless of aid marking. At nighttime, however, the turnmarking is critical because the cutoff is not used unless it is completely marked. For best results at night, it is recommended that three lighted buoys be used to mark the turn. Unlighted buoys are best used in the straightaways where they will not cause unnecessary maneuvering.

4.3 PILOT PERFORMANCE IN MODIFIED RUMSTICK NECK REACH

The change made in Rumstick Neck Reach was that three sets of gated buoys were removed (unlighted Buoys "11", "12", "15" and "16", and lighted Buoys "13 and "14") and replaced by two sets of lighted buoys (Buoys "11", "12", "15" and "16"). This modification resulted in more lighted buoys at night with fewer gated buoys spaced at wider intervals in the day.

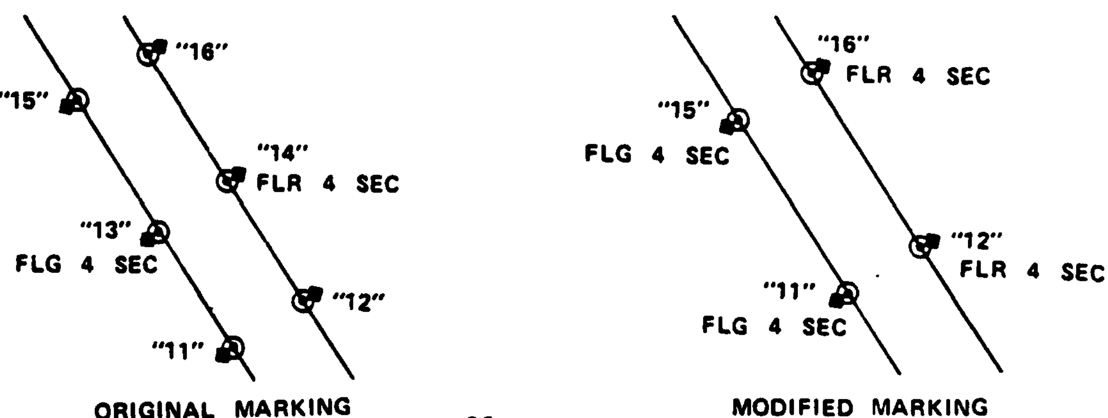


TABLE 8. AT-SEA DATA: PERFORMANCE IN POPASQUASH POINT TURN

	Pre-Aid Change - Day			Post-Aid Change - Day		
	Feet From Turn Apex	Mean	Standard Deviation	Feet From Turn Apex	Mean	Standard Deviation
Lower Entrance	2375	12R	42	2375	8L	31
	1425	41R	25	1425	21R	34
	0	179R	33	0	139R	82
Upper Entrance	950	128R	55	950	103R	50
	1425	117R	63	1425	100R	49
	2375	93R	64	2375	62R	42

	Pre-Aid Change - Night			Post-Aid Change - Night		
	Feet From Turn Apex	Mean	Standard Deviation	Feet From Turn Apex	Mean	Standard Deviation
Lower Entrance	2375	27L	96	2375	26R	60
	1425	26L	97	1425	57R	34
	0	72R	57	0	160R	34
Upper Entrance	950	50R	68	950	135R	64
	1425	39R	64	1425	108R	66
	2375	5R	70	2375	107R	55

Means and standard deviations are in feet from the center of the straight segment.

The rationale for this modification was that with the original marking of the 2.2 nm reach, in the day pilots had three sets of gates marking the channel, while at night pilots had one set of lighted gates and two sets of unlighted gates marking the channel. As discussed in Section 3, the Coast Guard planned to remove three of the unlighted buoys and keep the two lighted buoys in the middle of the reach. This modification would have resulted in a reduction of buoys. The pilots, however, protested the loss of two sets of buoys in unlighted gates because of local adverse conditions. There are shoals to either side of the channel and they said they used the gates on radar in meeting situations. There is also a sharp, S-shaped turn farther up in the channel (Conimicut Point Reach), so pilots prefer to pass traffic before or after Conimicut Point Reach. These features can be seen in Figure 4.

As a compromise, two sets of unlighted buoys were removed and a set of lighted buoys were added resulting in two lighted gated buoys marking the channel. This modification tests the draft manual prediction that gate spacing does not affect performance.

It was hypothesized that if gated buoys mark a channel, a change in buoy spacing would not affect performance. In the daytime the increase in lighted buoys and the change in buoy spacing is not expected to affect performance. At night, however, it is expected that there will be an improvement in the turn performance onto Rumstick Neck Reach because the lighted gates are closer to the turn. Therefore, nighttime performance will be closer to that found in the day. When trackkeeping, however, there should be no improvement in nighttime performance, and there should be no differences between day and night performance.

Performance in Rumstick Neck Reach is summarized by Table 9. The first data point represents the turn pullout and the second data point represents turn recovery. Trackkeeping performance can be evaluated between 0.6 to 1.0 nm into the leg (the leg is 2.2 nm long). Combined mean and standard deviation track plots of at sea data appear in Appendix D for the original channel and Appendix E for the modified channel.

Daytime performance was as hypothesized with no obvious differences due to aids in the straight leg. The pre-aid arrangement was three sets of gated buoys spaced at approximately 0.54 nm intervals through the 2.2 nm reach. The post-change arrangement was two sets of gates spaced approximately 0.6 nm apart with one gate 0.85 nm from the turn onto Rumstick and the other gated 0.7 nm from the turn onto Conimicut Point (see Figure 4). Both mean tracks were within 50 feet of centerline and the standard deviations were small. The similarity in performance demonstrates the draft manual assumption that a change in gated buoy spacing would not affect daytime performance.

The nighttime comparison between pre-aid and post-aid changes shows some similarities and some differences in performance. Overall, pre-aid and post-aid nighttime performance was similar with means within 50 feet of centerline and standard deviation small throughout most of the run. This supports the implementation hypothesis of no difference in straight leg performance as a result of changing gated buoy spacing. However,

TABLE 9. AT-SEA DATA: PERFORMANCE IN RUMSTICK NECK REACH

Pre-Aid Change - Day			Post-Aid Change - Day		
nm along Channel	Mean	Standard Deviation	nm along Channel	Mean	Standard Deviation
0.2	37L	33	0.2	53L	9
0.3	11R	17	0.3	43L	20
0.6	1R	19	0.6	20L	30
1.0	14L	29	1.0	14L	20

Pre-Aid Change - Night			Post-Aid Change - Night		
nm along Channel	Mean	Standard Deviation	nm along Channel	Mean	Standard Deviation
0.2	21L	30	0.2	54L	22
0.3	29R	52	0.3	14L	5
0.6	25R	36	0.6	55R	59
1.0	40R	63	1.0	6R	36

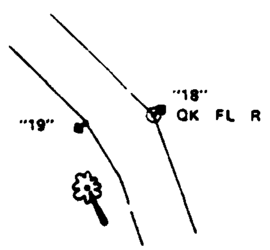
Means and standard deviations are in feet from the centerline of the channel.

performance is slightly worse at night than it is during the day. It is interesting that post-aid changes resulted in differences between day and night performance that weren't there before the aid change. Figure 3 shows day/night performance differences in Rumstick Neck Reach for both pre- and post-aid changes. As can be seen, the means are more different with the post-aid change arrangement. This may be due to gated buoys "11" and "12" set about 0.7 nm back from the turn. Therefore, the pilots do not have a pullout buoy to help them recover from the turn. This is more of a problem at night where there are fewer depth perception cues. Performance is slightly better with the pre-change arrangement. Possible explanations are either the pilots can see the unlighted buoys, or more likely they are more careful to avoid hitting these buoys.

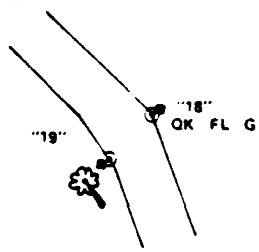
It can be concluded that performance in straight legs is not affected by gated buoy spacing. It is suggested, however, that gated buoys (or another aid) be placed so they provide pullout information for turns which connect straight legs. This is particularly true for large turn angles such as the 37-degree turn onto Rumstick Neck Reach. This suggestion is consistent with experimental simulator data and discussions with pilots regarding Rumstick Neck Reach buoy requirements. For more details see Postimplementation Draft Principal Findings Report.[15]

4.4 PERFORMANCE IN MODIFIED TURN ONTO CONIMICUT POINT REACH

The change made in the turn onto Conimicut Point Reacn was that unlighted Buoy "19" was removed and replaced by a lighted buoy. The buoy was moved approximately 1000 feet to be opposite Buoy "18". This modification results in a gated two-buoy turn that marks the edge of the channel.



ORIGINAL MARKING



MODIFIED MARKING

The rationale for this modification is that the 18-degree cutoff turn into Conimicut Point Reach was marked on one side by a lighted buoy and on the other side by a lighted beacon located some distance off the edge of the channel. In the day, pilots can use unlighted Buoys "19" and "21" (see Figure 4) in conjunction with the beacon to determine the left boundary, but at night only Buoy "18" identifies the channel boundary. The draft design manual stresses the importance of outlining the boundaries of the turn. This is not accomplished by the original aids. Therefore, Buoy "19" was lighted and located at the turn apex to identify the left channel boundary and Buoy "18" identifies the right channel boundary.

[15]K.L. Marino, J.D. Moynehan, J. Multer, and M.W. Smith. "Aids to Navigation Implementation At-Sea Postimplementation Draft Principal Findings." Washington, D.C., October 1984.

It was hypothesized that both day and night performance will improve because there are two lighted buoys instead of one marking the extremities of turn. It was further hypothesized that this improvement will be greater at night because the availability of fewer secondary aids and objects, and poorer depth perception create more of a problem at night.

Performance in Conimicut Point Reach is summarized by Table 10. Combined mean and standard deviation tracks plots of at-sea data appear in Appendix D for the original channel and Appendix E for the modified channel. During daytime transits, pilots did not have much problem negotiating the 18-degree turn before or after the aid change. The new aid arrangement resulted in a mean that is closer to the centerline. The post-aid standard deviation is smaller than that of pre-aid but it is jumpy, possibly a result of a small sample.

At night, performance is somewhat worse than that found in the daytime. Lighting and moving Buoy "19" to form a two-buoy turn results in maneuvering closer to the inside of the turn, making a less drastic maneuver. At night, the mean track improved after the aid change, however, the standard deviation was equivocal and probably supports a pullout buoy for difficult turns. This turn is difficult even though the angle is not large because it is the beginning of an S-shaped turn over a short distance. With the pre-aid arrangement the standard deviation was high in both turns surrounding Conimicut Point Reach. With the post-aid arrangement, the standard deviation was higher in the turn onto Conimicut Point, but it was smaller in the turn onto Bullock Point Reach. This may be due to the aid change since the mean is closer to the left, the ship is positioned to make the second turn more gradually.

Most of the pilots preferred the new arrangement because it better defined the turn. This turn is critical as can be seen by a chart of the area because it is the start of an S-shaped turn that is surrounded by shoaling, particularly at the turn apex. It can be concluded then, that lighting Buoy "19" is helpful for piloting.

4.5 SUMMARY

In an effort to evaluate the implementation of draft manual recommendations, aid changes were made in Popasquash Point Turn, Rumstick Neck Reach, and Conimicut Point Turn. Each of these changes was expected to improve performance in the Upper Narragansett Bay.

The first change was to light Buoy "4" off Popasquash Point to create a three-buoy turn, day and night. It was expected this change would make day and night performance more similar, that is, it would improve nighttime performance but not impact daytime performance. Performance was as hypothesized. It can be concluded that pilots use the cutoff in the day regardless of aid marking. At night, however, the turnmarking is more critical because the pilots will use only the part of the turn that is marked.

The second change was to modify the gated buoy spacing in Rumstick Neck Reach to test the draft manual prediction that gate spacing does not impact

TABLE 10. AT-SEA DATA: PERFORMANCE IN CONIMICUT POINT TURN

	Pre-Aid Change - Day			Post-Aid Change - Day		
	From From Turn Apex	Mean	Standard Deviation	Feet From Turn Apex	Mean	Standard Deviation
Rumstick Neck Reach	1425	48L	27	1425	6R	31
	475	48L	41	475	0	28
	0	68L	46	0	4L	1
Conimicut Point Reach	475	72L	46	475	79L	1
	950	31L	49	950	61L	5
	1425	9L	51	1425	28L	41

	Pre-Aid Change Night			Post-Aid Change - Night		
	From From Turn Apex	Mean	Standard Deviation	Feet From Turn Apex	Mean	Standard Deviation
Rumstick Neck Reach	1425	9R	76	1425	30R	137
	475	12R	90	475	6L	100
	0	10L	75	0	40L	111
Conimicut Point Reach	475	24R	34	475	91L	77
	950	60R	12	950	51L	73
	1425	68R	18	1425	43L	84

Means and standard deviations are in feet from the centerline of the channel.

performance. Three sets of gated buoys were replaced by two sets of lighted buoys. Daytime performance was as hypothesized with no differences in performance due to buoy spacing. However, nighttime performance did not improve as much as expected. As a result of the buoy changes, there are day/night differences in performance that were not there before the aid change. It appears this is due to buoy spacing in relation to the turns rather than the buoy spacing between the gates in the straight leg. Rumstick Neck Reach is 2.2 nm long and joins the Upper Entrance channel by a 35-degree turn and Conimicut Point Reach by an 18-degree turn. The first gated Buoys "11" and "12" are placed 0.85 nm from the turn so the buoys did not help in the turn pullout. Nighttime performance was better with the original arrangement which had two unlighted buoys placed closer to the turn. Possible explanations are either the pilots can see the unlighted buoys or they are careful to avoid hitting these buoys. It can be concluded that performance in straight legs is not affected by gated buoy spacing. However, it is suggested that gated buoys be placed so they provide pullout information for turns which connect the straight legs.

The change made in the turn onto Conimicut Point Reach was that Buoy "19" was lighted and moved south to be perpendicular with Buoy "18". This resulted in the apex of the turn and the turn extremities being marked. This is importance since the turn is surrounded by shoals. During daytime transits pilots did not have much problem negotiating the 18-degree turn before or after the aid change. The new aid arrangement resulted in better performance. Nighttime performance was somewhat worse than that found in the daytime. Although the mean is closer to the left, the ship is positioned to make the second turn off Conimicut more gradually due to this position. Lighting Buoy "19" is crucial because of the shoaling surrounding the turn and because short Conimicut Point Reach (0.1 nm) connects two sharp turns forming one S-shaped turn.

Section 5
SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 SUMMARY

A major objective of the Implementation task was to develop the methodology to achieve implementation of findings in the short range aids to navigation research area. Part of this process was to: (1) identify aids to navigation design and placement problems existing in the real world; (2) make improvements based on draft manual recommendations, pilot preference, and local conditions; and (3) evaluate the impact of these changes on performance. The Upper Narragansett Bay was selected as the real waterway to implement aid changes as recommended by the draft manual.

For the implementation in the Narragansett Bay, information was collected from five sources. First, at-sea data was collected in the originally marked channel to acquire a baseline by which to evaluate the alternative aid arrangements. Secondly, the channel was modeled on the simulator to evaluate aid alternatives in a "safe" environment. The alternatives were designed for "efficiency" to provide the greatest effectiveness for the smallest number or buoys or other aids and for "economy" or low cost. Third, the draft manual was further applied to identify alternatives designed for "effectiveness" to provide maximum precision of performance. Fourth, input from members of the local pilots association was solicited to obtain "local knowledge" that is unattainable by reviewing charts. It identifies piloting hazards, concerns, and preferences. Finally, the Coast Guard reviewed all data to identify and manage risk. The aid system selected was designed to balance efficiency, economy, and effectiveness.

Aid changes were made in Popasquash Point Turn, Rumstick Neck Reach, and Conimicut Point Turn. (Charts showing the changes appear in Section 4 on pages 24 and 25.) In Popasquash Point Turn, the 15-degree cutoff was originally marked by two lighted buoys and one unlighted buoy. The unlighted buoy was replaced by a lighted one. Although it is a low angle turn, the three lighted buoys are useful at night because Popasquash Point is isolated and lacks background lighting. It was found that in the day pilots use the cutoff regardless of its marking. At night, however, turnmarking is more critical because the cutoff is not used unless it is completely marked. Unlighted aids are not useful in the turns and are potentially harmful because they must be avoided. In Rumstick Neck Reach the original marking was three sets of gated buoys with one set lighted and remaining two unlighted. After the changes, two sets of lighted gated buoys marked the 2.2 nm channel. It was found that changing gated buoy spacing had no impact on performance in the straight leg, however, gate spacing and its relation to the turn affects performance. It was found that in Rumstick Neck Reach, there was no pullout buoy because the first gate was placed 0.85 nm after the turn. This did not affect daytime performance, but nighttime performance was slightly worse than before the aid change. In the turn onto Conimicut Point Reach the original marking for the 18-degree turn was one buoy marking the turn extremity, Buoy "19" which was unlighted and placed after the inside apex of the turn, and a sector light located some distance off the channel edge. Only Buoy "19" was modified. It was moved south to

mark the inside apex of the turn and lighted. It was found that in the daytime performance was good before and after the aid change. At night, the mean improved after the aid change; however, the standard deviation was equivocal and probably supports a pullout buoy for difficult turns. This turn is difficult even through the angle is not large because it is the beginning of an S-shaped turn over a short distance.

5.2 CONCLUSIONS AND RECOMMENDATIONS

One intention of the Implementation task was narrow. The plan was to change aids in Narragansett Bay based on draft manual recommendations and "test" the recommendations by comparing at-sea tracks in the pre- and post-change channels. It was found that performance in the post-change channels was as hypothesized. (Specific hypotheses and performance comparisons can be found in Section 4.2, 4.3, and 4.4. This data is also summarized in Section 5.1.) This verifies the soundness of basic assumptions built into the draft manual. Specific conclusions included the following.

- Best results at night occur when three unlighted buoys mark turn cutoffs of critical turns. These include large angle turns or turns without natural aids or background cultural lights.
- Pilots use the cutoff turn in the day regardless of how it is marked, but make full use of a cutoff at night only if it is clearly marked.
- Performance in the straight legs is not affected by gated buoy spacing. In a turn, however, if there is no pullout buoy, the first gated buoys should be placed near the turn.

The benefits of Implementation task have been broader than the test of the design guidelines. It was found that as written, the draft manual was too rigid. It was based too closely on a series of simulator experiments with simplified waterways. It considered such factors as aids to navigation and the waterway, specifically channel width, channel depth, length of leg, turn angle, and type of turn (cutoff or noncutoff). However, it did not allow sufficiently for other factors such as channel surroundings, traffic, weather, ecology of waterway, population identification, and local user input (pilot association members may be most knowledgeable and informative). As a result of the Implementation task in Narragansett Bay, the following changes will be made.

- The final design manual will be more flexible and will enable the user to adapt the guidelines to unique conditions.
- The final design manual will be less conservative and more accepting of a variety of channel markings.

The Implementation task spotlighted the difference between risk assessment and risk management. The design recommendations and evaluation procedures in the draft manual that are experimentally derived provide a risk assessment process. Risk management includes selecting criteria for redesigning an aid system, obtaining data on conditions that are unique for a particular waterway, and identifying ramifications of user needs. Three

different criteria were used in applying the draft manual in the Narragansett Bay. These included effectiveness, efficiency, and economy. Depending upon the emphasis of these criteria, recommended aid arrangements varied. The criteria and the alternative arrangements are identified and discussed in Section 3.1. Experience during the Implementation task leads to the recommendation that risk management considerations come early in any implementation process. The following order of steps is recommended:

1. Selection of Coast Guard criteria for risk management
2. Consideration of local conditions and pilots' preferences
3. Manual design and evaluation of alternatives
4. Consideration of trade-offs among all factors
5. Simulator evaluation for difficult choices (optional)
6. Change in aid system

Appendix A

SUMMARY OF PILOT OPINIONS ON NEW CHANNEL MARKINGS

The following discussion summarizes pilot response to a structured questionnaire regarding aid modifications in the Narragansett Bay. Nine pilots were interviewed to solicit their opinions on the aid changes in Popasquash Point Turn, Rumstick Neck Reach, and Conimicut Point Turn. The original channel is shown by Figure A-1 and the modified channel is shown by Figure A-2.

In Popasquash Point Turn, Buoy "4" was lighted to make a three-buoy turn at day and night. All but one pilot preferred this new arrangement because now at night the buoy configuration was identical to that found during the day. The pilots stated that with the original arrangement the main danger was hitting the unlighted buoy at night. With the new arrangement, they no longer had to pull the inbound ship to the left to avoid the buoy. In addition, the lighted buoy was helpful in meeting traffic. One pilot, however, did not find the new buoy helpful since he used Buoy "5", the buoy in the turn apex, to conduct the turn.

In Rumstick Neck Reach, three sets of gated buoys (unlighted Buoys "11" and "12", lighted Buoys "13" and "14", and unlighted Buoys "15" and "16") were removed and replaced by two sets of lighted gated buoys. This resulted in more lighted buoys at night with fewer gated buoys spaced at wider intervals in the day. Only one pilot preferred the new arrangement, three pilots preferred the original arrangement, and the remaining five pilots were indifferent. The pilot who preferred the new arrangement considered it especially helpful at night since the unlighted buoys, which were hazardous at night, were eliminated. Now that the pilot was sure of the channel edge, it was more helpful in a meeting situation. Three of the pilots did not like the new arrangement because the buoys were skewed north in the reach and were not equidistantly placed. This resulted in no recovery buoy because the buoys were placed too far up in the channel. The original arrangement was generally preferred because even though the buoys were unlighted, they could be seen on radar. The pilots explained that this reach has wind and current that sets the ship to the right so more buoys are needed here than in the Upper Entrance. These pilots thought the new buoy arrangement may be worse in a meeting situation because there is no recovery buoy to gauge the ship location in the channel. The five remaining pilots had no preference to the aid arrangements because in addition to buoys, they used other aids such as the sector light and radar. These pilots stated that the new arrangement would probably not affect their track or their performance in meeting traffic.

In Conimicut Point Turn, unlighted Buoy "19" was removed and replaced by a lighted buoy moved approximately 1000 feet south to line up with Buoy "18". Five pilots preferred the change since it better defined the turn. Interestingly one of these pilots said the "change may result in an illusion that it reduces space in the turn, but the space was never there anyway." This appears true because another four pilots were unhappy with the location of Buoy "19". They believed they lost a bit of the channel and had to make the turn sharper because of the relocated buoy. It is obvious by chart

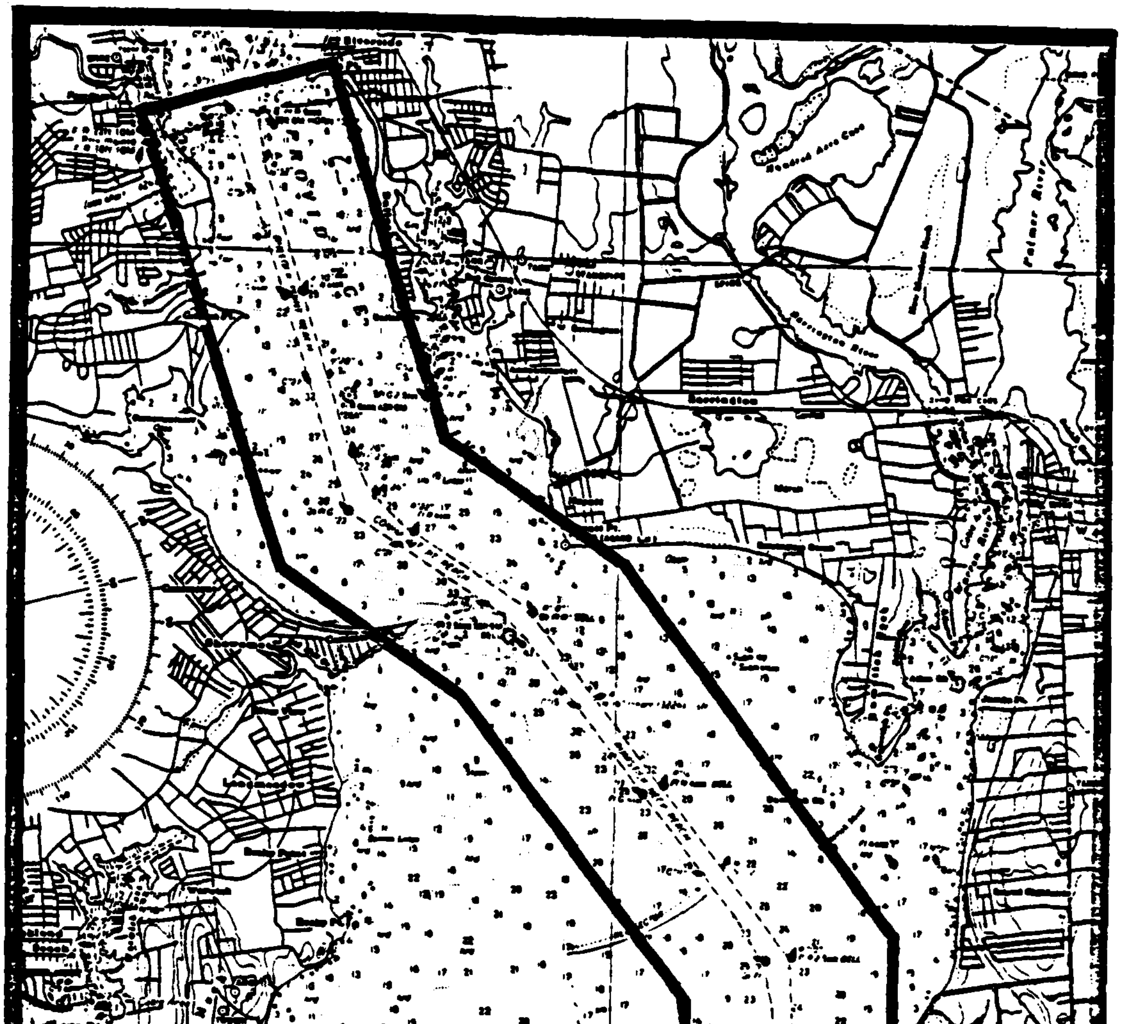


Figure A-1. Pre-aid Change Configuration in Upper Narragansett Bay (Chart 13221, March 28, 1981

Figure A-2. Modified Aid Configuration in Upper Narragansett Bay

examination that shoaling borders the inbound left channel boundary. As several pilots stated, the new buoy position ensures that the shoaling obstacle is avoided.

In summary, most pilots are pleased with the lighted buoys added to the turns of Popasquash Point and Conimicut Point. In Rumstick Neck Reach, however, some pilots were unhappy with the buoy spacing because they were skewed north in the reach and were not equidistantly spaced. Others pilots were indifferent to the changes made in Rumstick Neck Reach. The lack of consensus in response to the changes in Rumstick Neck Reach compared to the consensus in response to the other changes can be interpreted as support for the draft manual's prediction that performance is indifferent to the spacing of gates.

Appendix B

NARRAGANSETT BAY SIMULATOR TRACK PLOTS

This appendix contains pilot performance track plots of simulator data collected for the Narragansett Bay. Figure B-1 shows the original channel marking of Scenario 6. Figures B-2 and B-3 show the alternative channel markings of Scenarios 3 and 7 respectively. The data plotted shows performance for eight nighttime runs with the 30,000 dwt tanker model.

Table B-1 identifies the conditions represented by the track plots. The plots are grouped by location of data.

There are two types of track plots in this section. A combined plot is illustrated on page B-7. It consists of a series of three plots for one of the two channel legs. The axis for the abscissa is scaled so that one unit of alongtrack distance represents 475 feet (5/64 nm). The top plot displays the crosstrack mean and the middle plot displays the crosstrack standard deviation. The bottom plot is a combined plot showing the crosstrack mean and an envelope encompassing two standard deviations to either side, an area within which performance is expected to occur 95 percent of the time. A comparison plot is illustrated on page B-10. For each comparison there are two sets of axes, one showing the means of two conditions and one showing the crosstrack standard deviation as the performance measures. Data is plotted as a continuous unbroken line and a dotted line to distinguish the experimental conditions from each other.

Statistical tests were used to test the differences in performance at each data line, to determine if any differences between conditions were statistically significant. The means were compared using a t-test. The symbols along the axis of the mean plot indicate a difference at the 0.10 level of significance. The standard deviations were compared as variances using an F test. The symbols along the axis of the standard deviation plot also indicate a difference at the 0.10 level of significance.

Plot Notes:

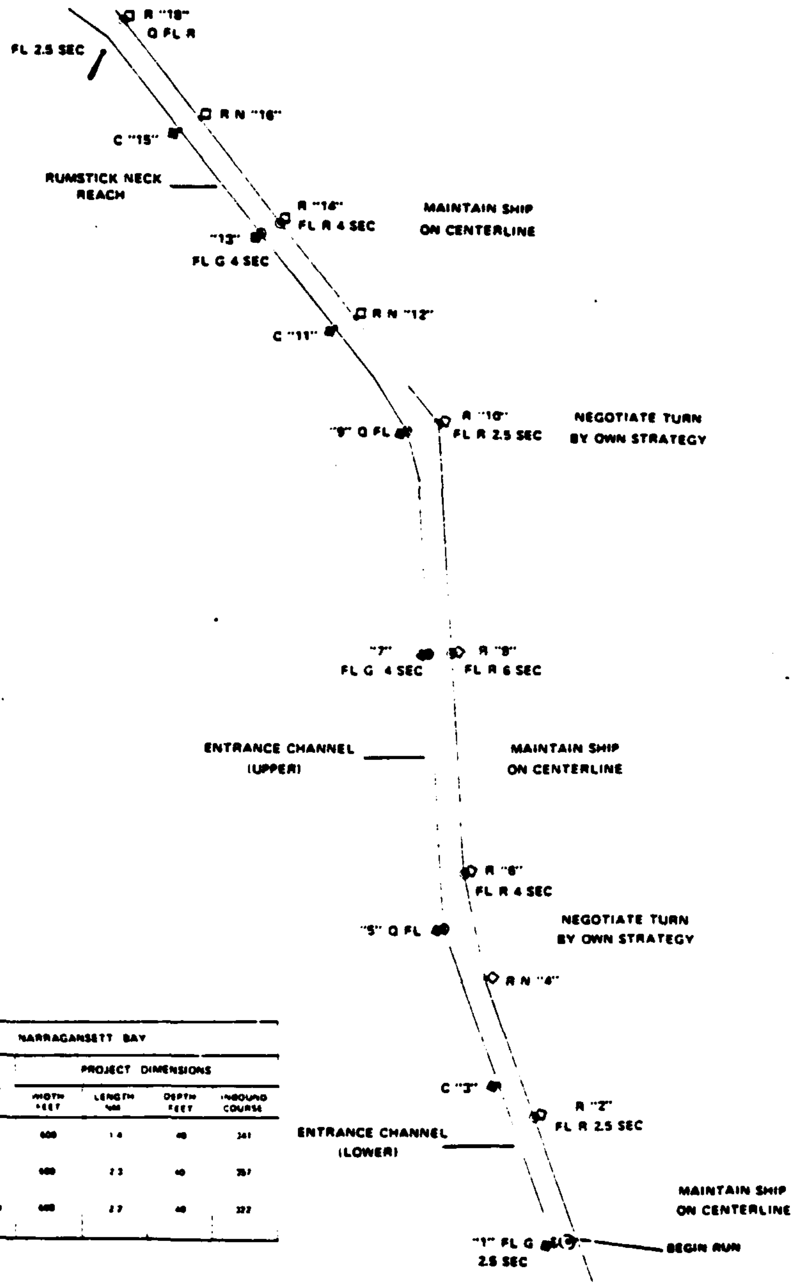
1. On the plots, buoys and lights are positioned for the purpose of illustration and may not appear in their exact charted location.

2. Aids to Navigation symbols

   - nun buoy
   - can buoy
   - red, lighted buoy
   - black, lighted buoy
   - light beacon

TABLE B-1. NIGHTTIME NARRAGANSETT BAY SIMULATION SCENARIOS

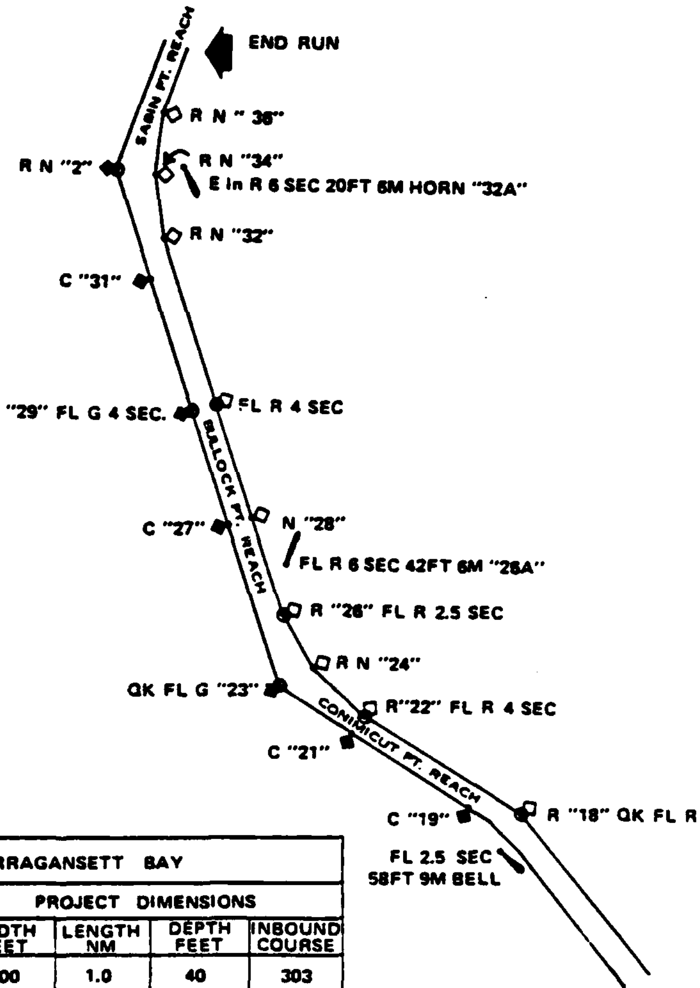
Page	Scenario	Channel	Condition	Plot
B-7	6	Lower Entrance Upper Entrance	Original	Combined
B-8	3	Lower Entrance Upper Entrance	3 buoy turn	Combined
B-9	7	Lower Entrance Upper Entrance	2 buoy turn	Combined
B-10	3 and 6	Lower Entrance Upper Entrance	Lighting Buoy 4 Versus original	Comparison
B-11	3 and 7	Lower Entrance Upper Entrance	Lighted Buoy 4 Versus Lighted Gate	Comparison
B-12	7 and 6	Lower Entrance Upper Entrance	Lighted gate versus original	Comparison
B-13	6	Rumstick Neck Reach Conimicut Point Reach	Original	Combined
B-14	3	Rumstick Neck Reach Conimicut Point Reach	Staggered 2 left, 1 right	Combined
B-15	7	Rumstick Neck Reach Conimicut Point Reach	Staggered 1 left, 2 right	Combined
B-16	3 and 6	Rumstick Neck Reach Conimicut Point Reach	Staggered 1 left, 2 right Versus original	Comparison
B-17	3 and 7	Rumstick Neck Reach Conimicut Point Reach	Staggered 2 left, 1 right Versus original	Comparison
B-18	7 and 6	Rumstick Neck Reach Conimicut Point Reach	Staggered 1 left, 2 right Versus 2 left, 1 right	Comparison



NARRAGANSETT BAY				
NAME OF CHANNEL	PROJECT DIMENSIONS			
	WIDTH FEET	LENGTH NM	DEPTH FEET	INBOUND COURSE
ENTRANCE CHANNEL LOWER	600	1.4	40	341
ENTRANCE CHANNEL UPPER	600	2.3	40	357
RUMSTICK NECK REACH	600	2.7	40	322

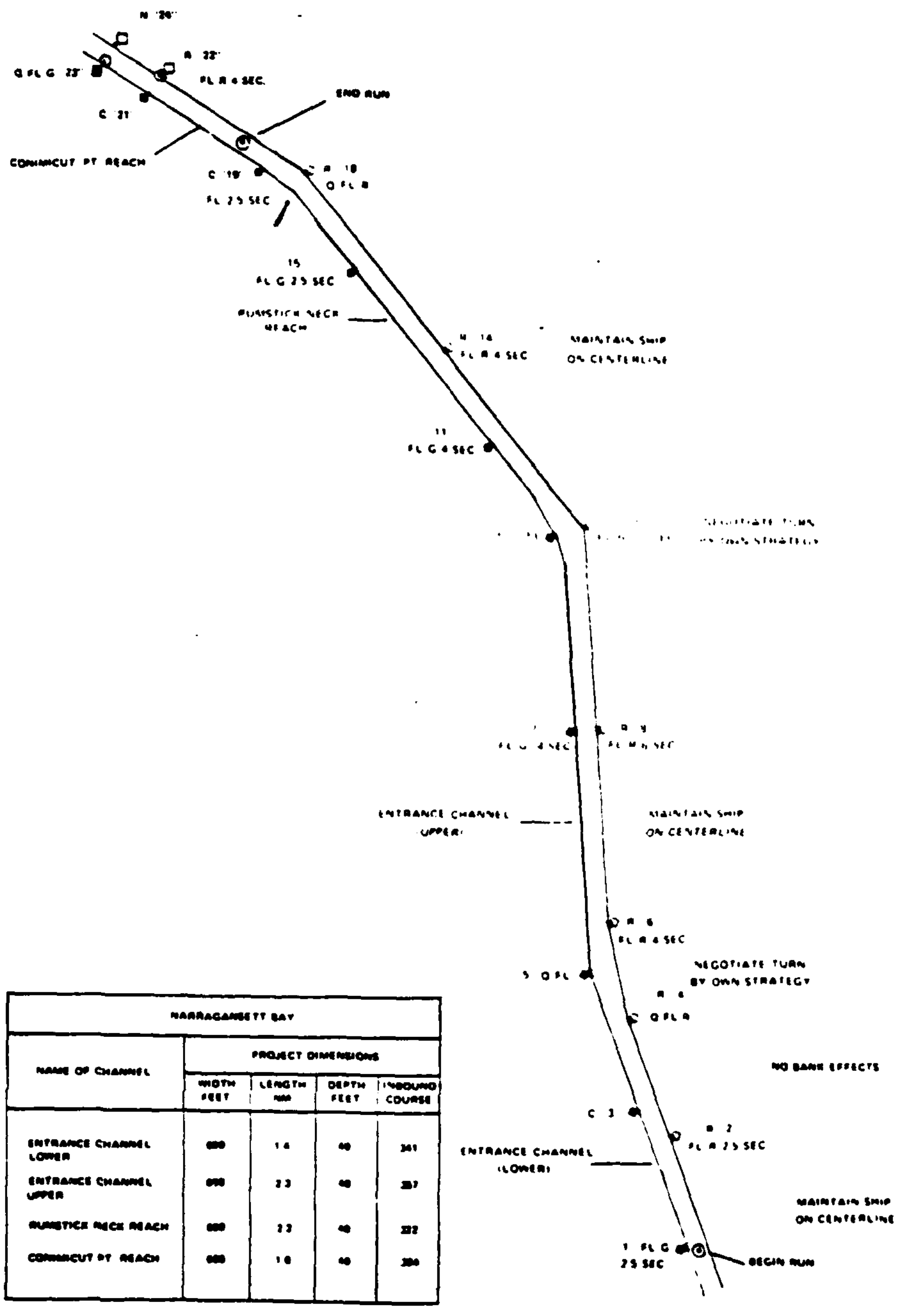
Figure B-1. Original Channel Marking

SIMULATION VALIDATION II



NARRAGANSETT BAY				
NAME OF CHANNEL	PROJECT DIMENSIONS			
	WIDTH FEET	LENGTH NM	DEPTH FEET	INBOUND COURSE
CONIMICUT PT. REACH	600	1.0	40	303
BULLOCK PT. REACH	600	2.1	40	343
SABIN PT. REACH	600	0.8	40	020

Figure B-1. Original Channel Marking (Continued)



NARRAGANSETT BAY				
NAME OF CHANNEL	PROJECT DIMENSIONS			
	WIDTH FEET	LENGTH NM	DEPTH FEET	INBOUND COURSE
ENTRANCE CHANNEL LOWER	[illegible]	1.4	40	341
ENTRANCE CHANNEL UPPER	[illegible]	2.3	40	357
RUMSTICK NECK REACH	[illegible]	2.2	40	332
CONANICUT PT REACH	[illegible]	1.6	40	[illegible]

Figure B-2. Alternative Channel Marking, Night (Scenario 3)

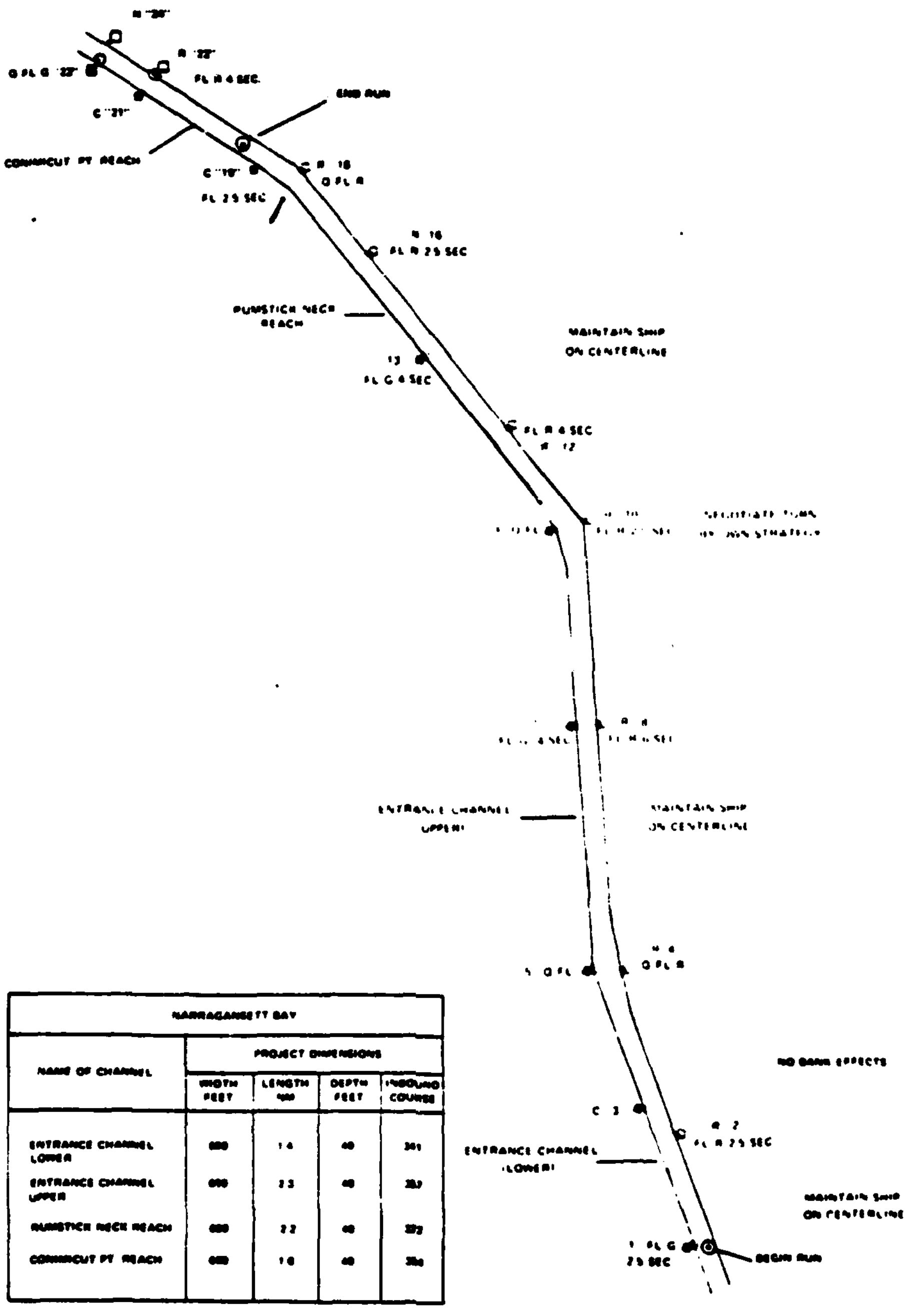


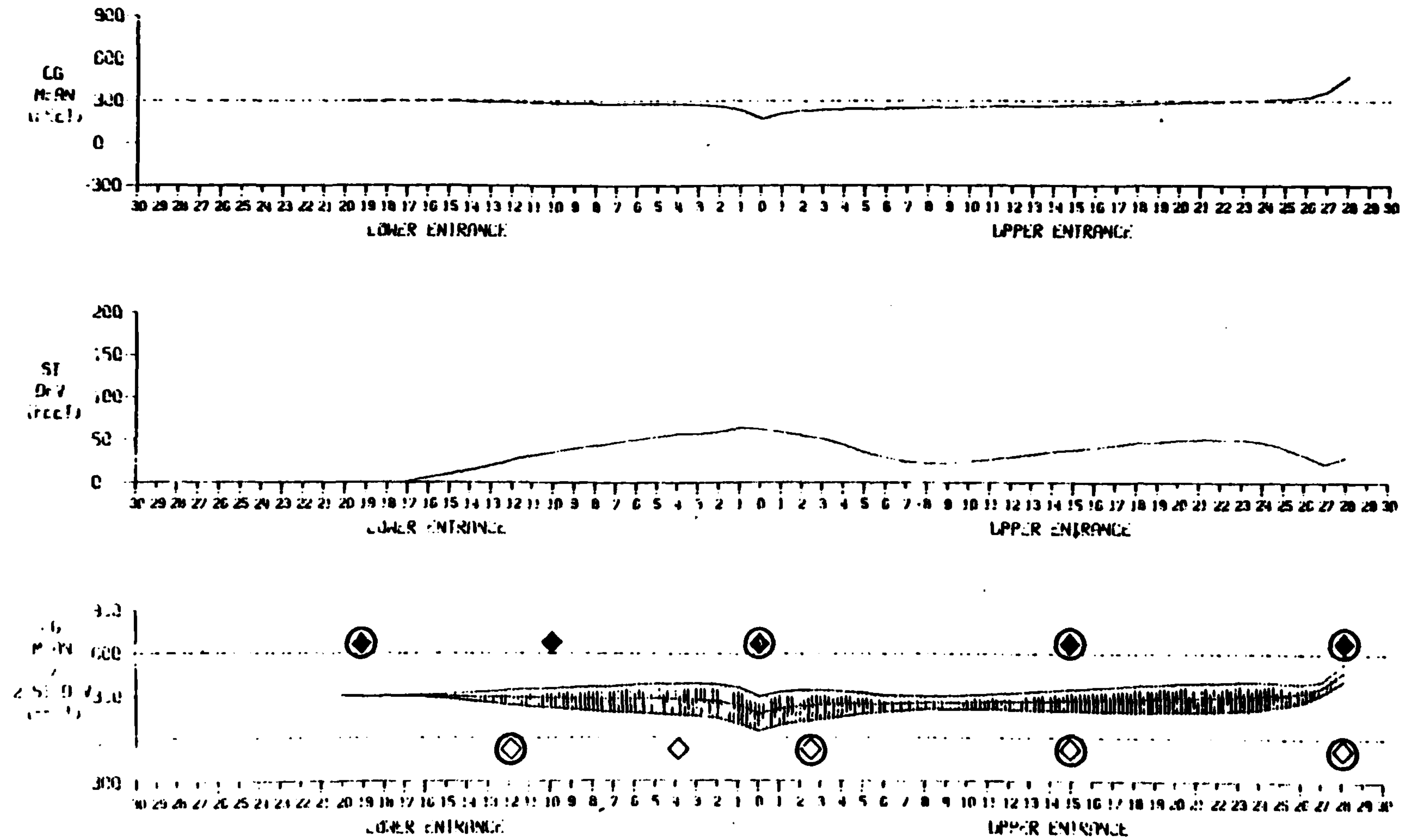
Figure B-3. Alternative Channel Marking, Night (Scenario 7)

Scenario 6

VALIDATION

NARRAGANSETT

NIGHT

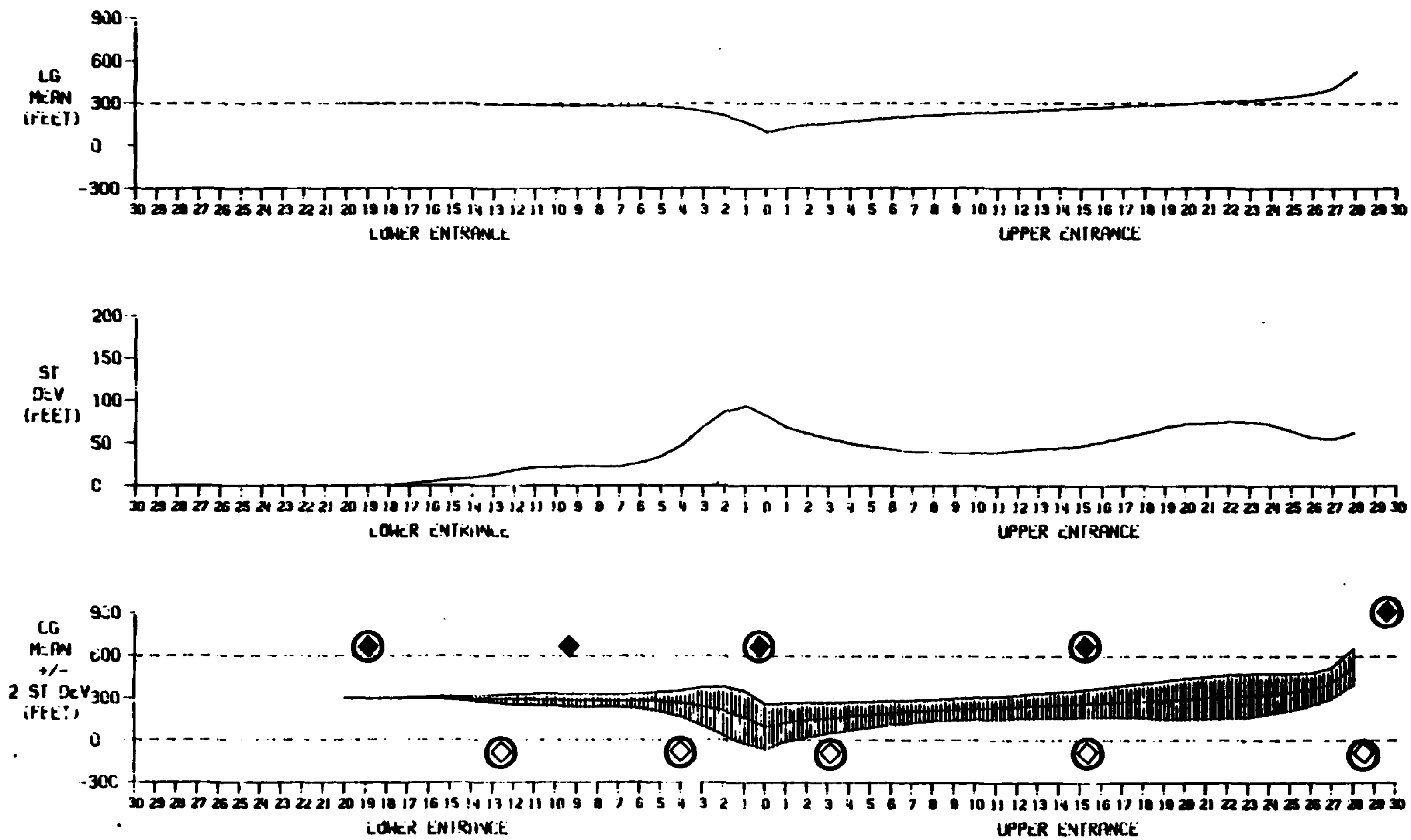


Scenario 3

IMPLEMENTATION

POPASQUASH TURN-NIGHT

LIGHTING BUOY 4

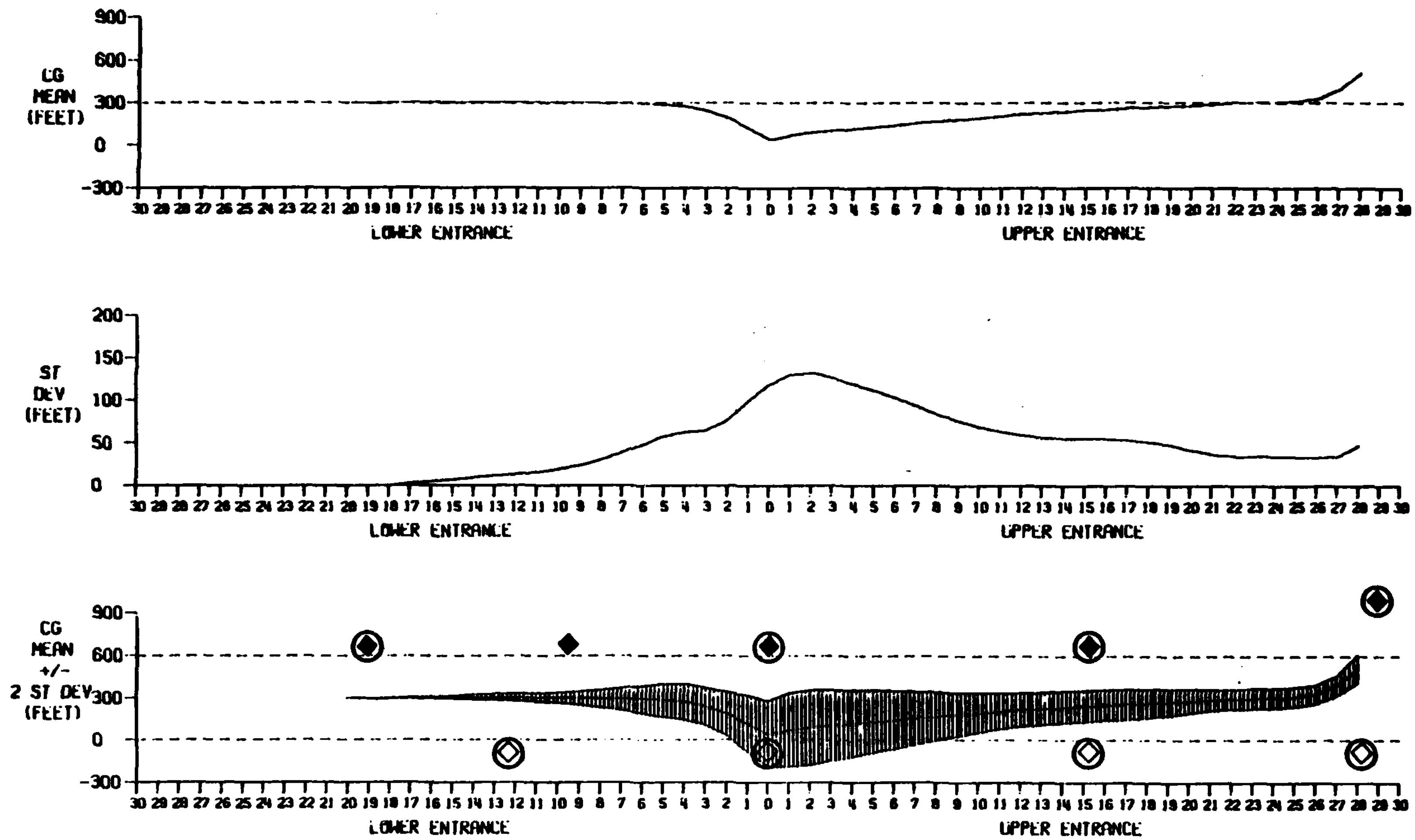


Scenario 7

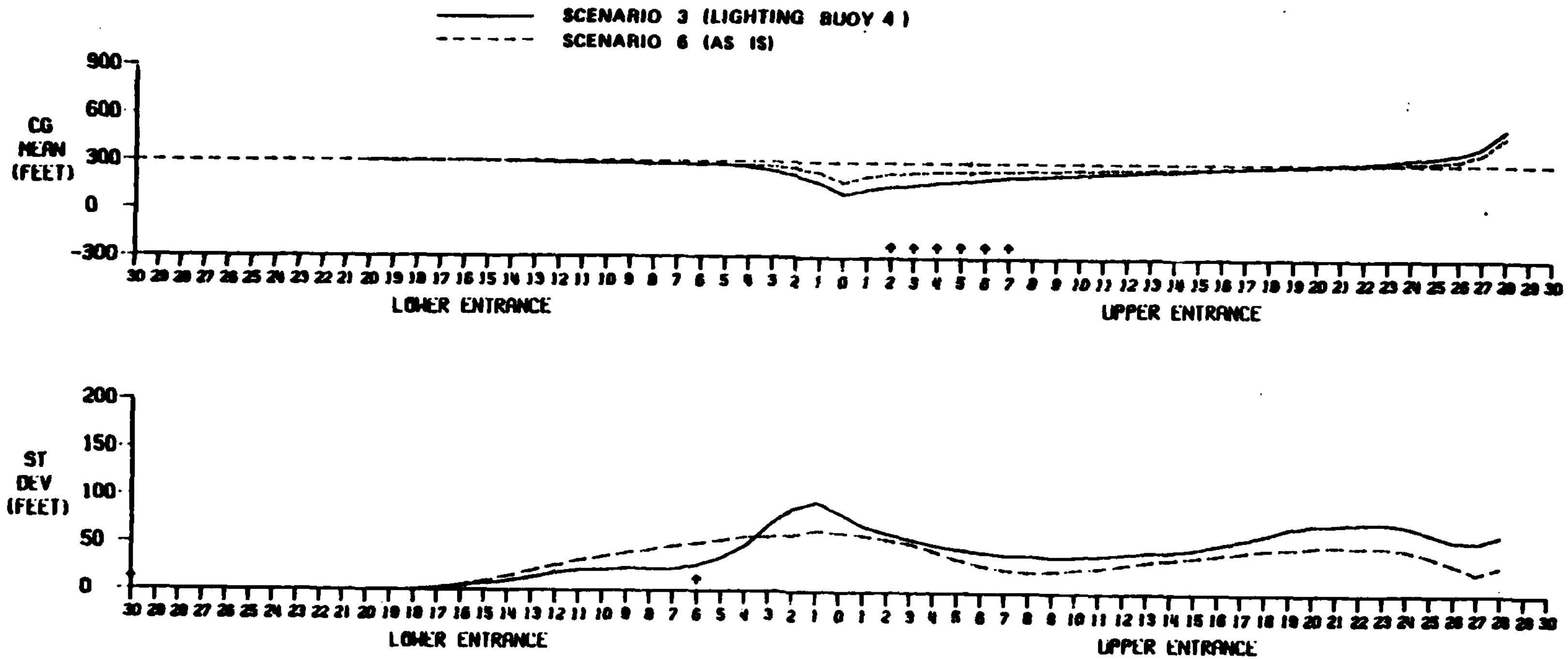
IMPLEMENTATION

POPASQUASH TURN-NIGHT

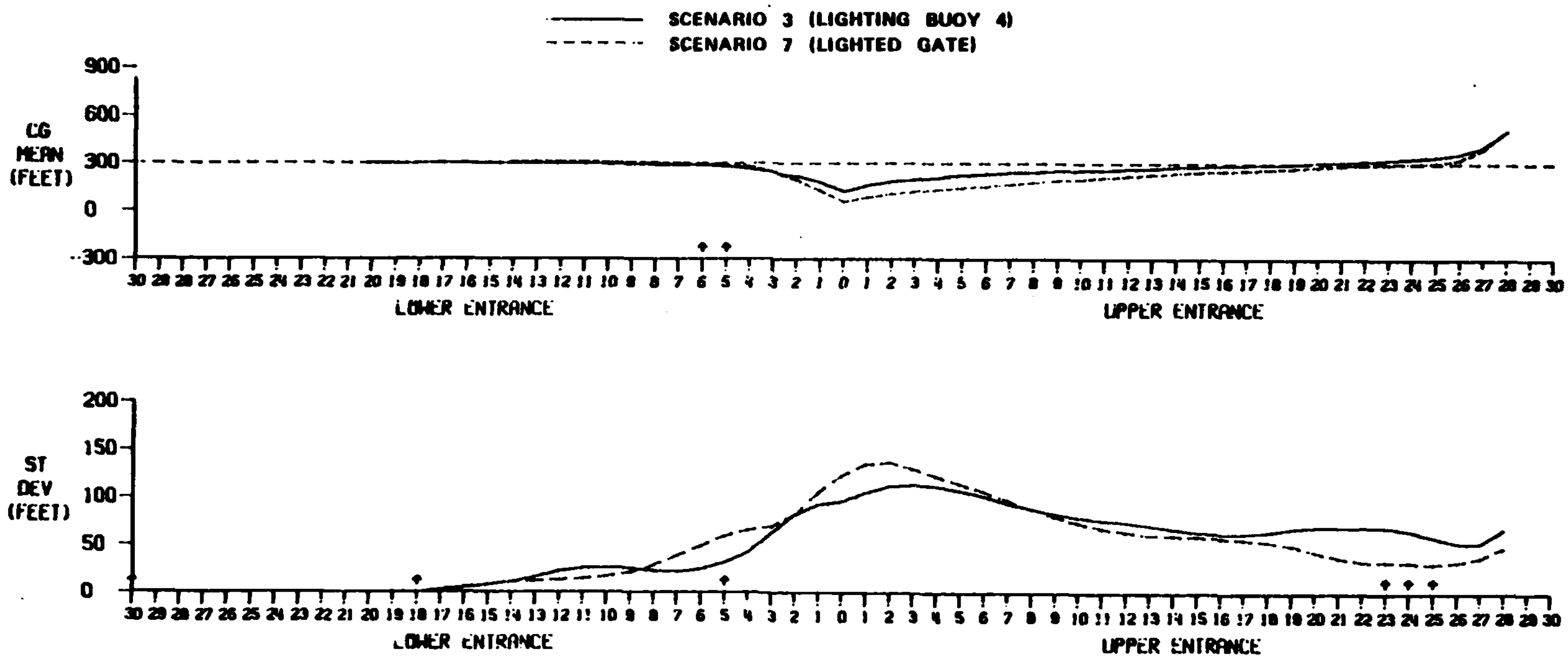
LIGHTED GATE



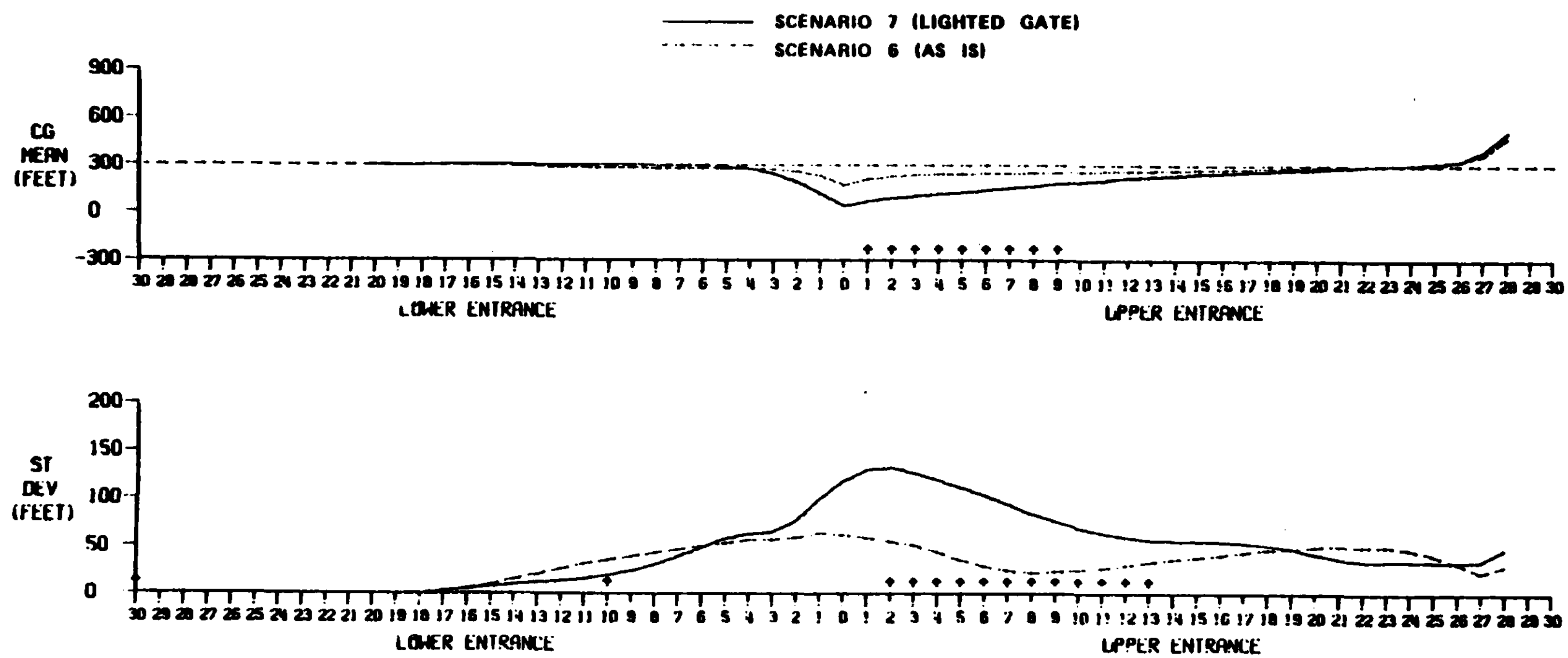
LIGHTING BUOY 4 VS. AS IS
NIGHT



LIGHTING BUOY 4 VS. LIGHTED GATE
NIGHT



LIGHTED GATE VS. AS IS
NIGHT

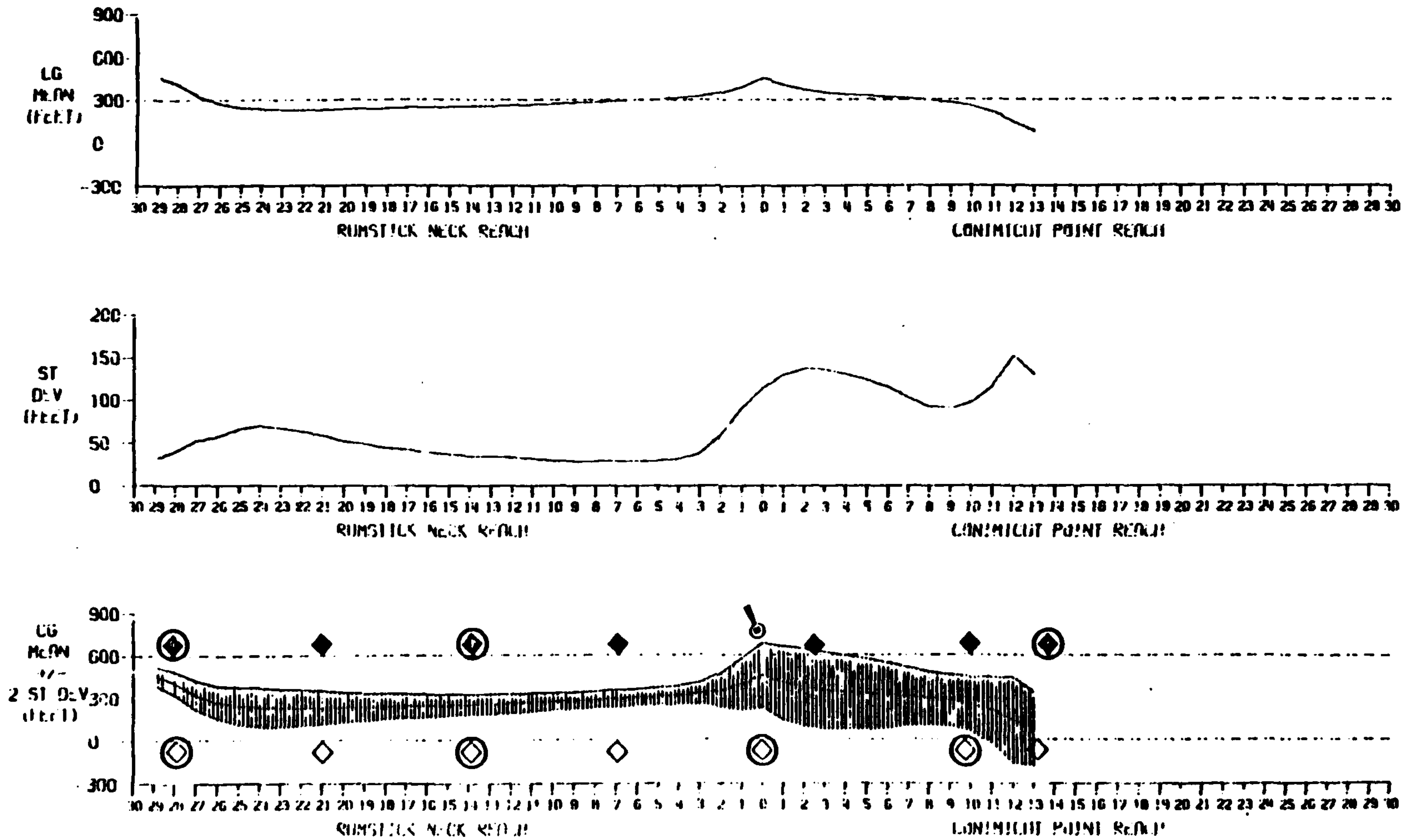


Scenario 6

VALIDATION

NARRAGANSETT

NIGHT

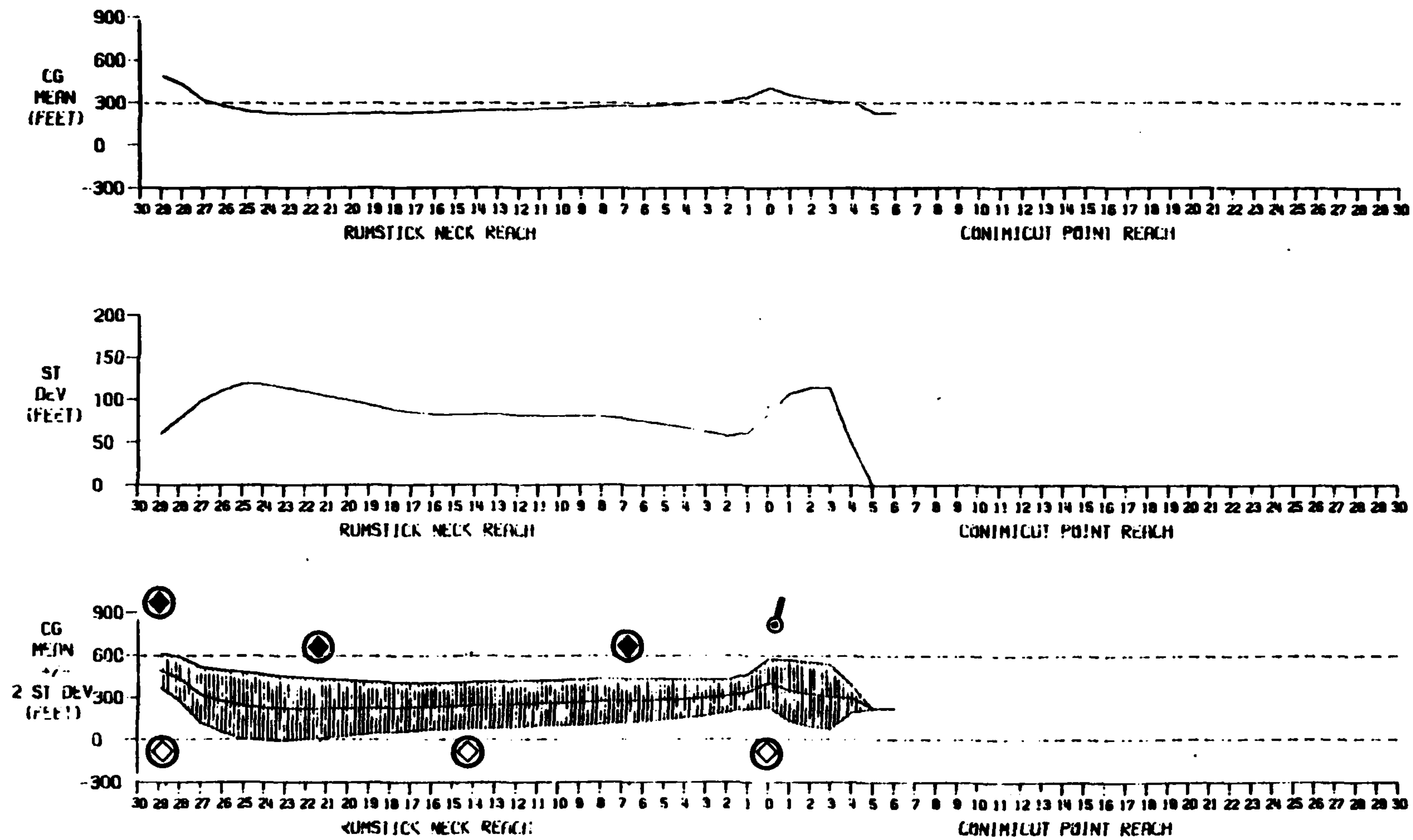


Scenario 3

IMPLEMENTATION

RUMSTICK NECK - NIGHT

LIGHTED, STAGGERED INSIDE

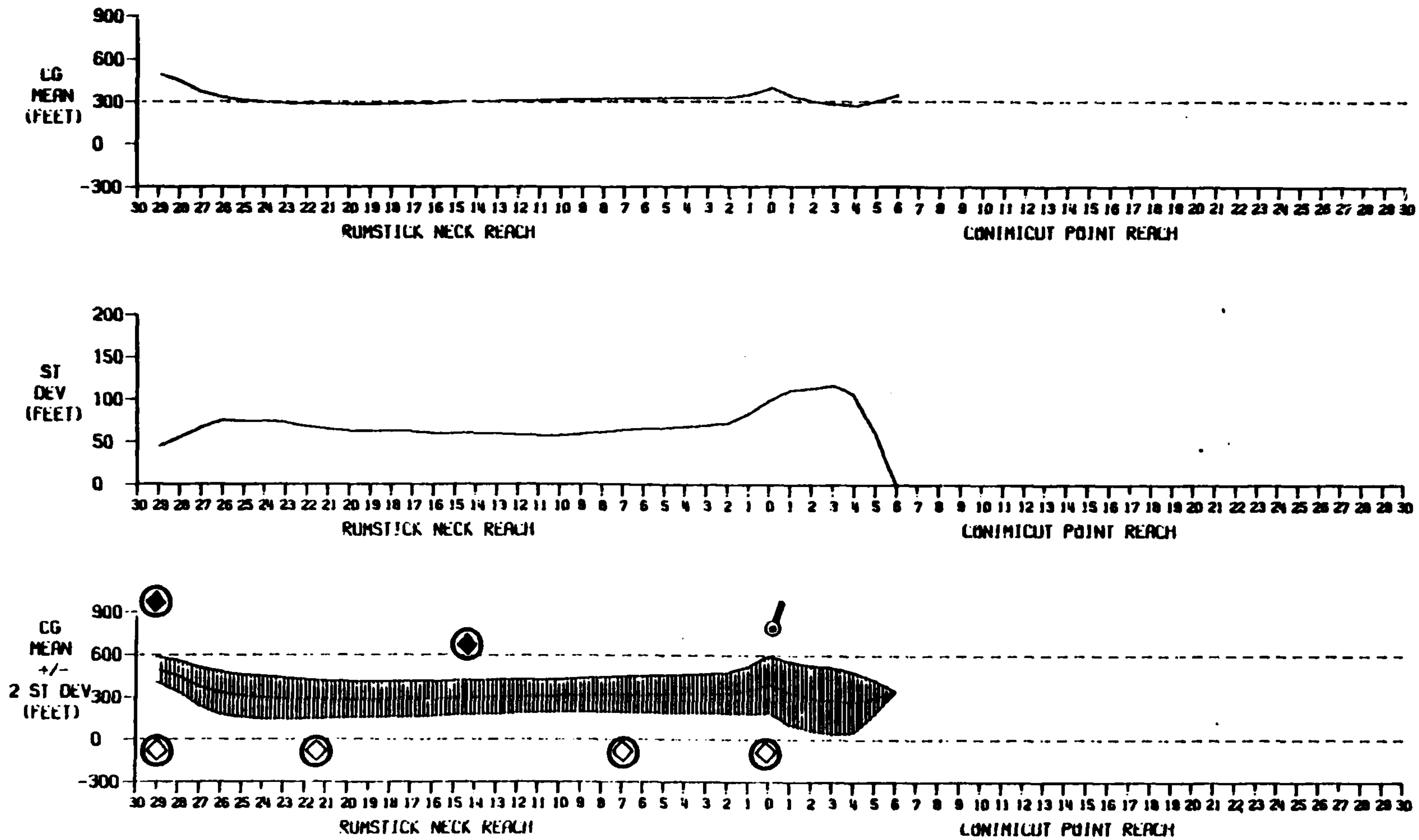


Scenario 7

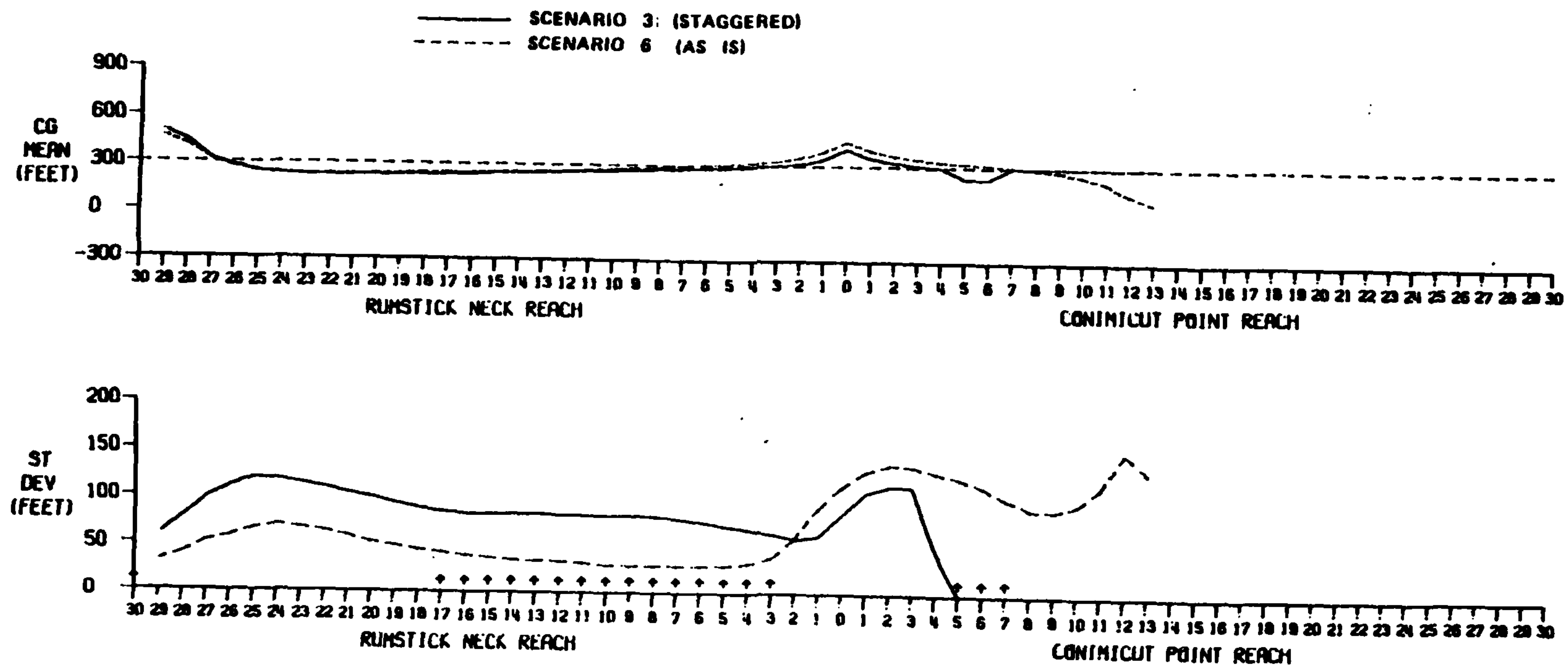
IMPLEMENTATION

RUMSTICK NECK - NIGHT

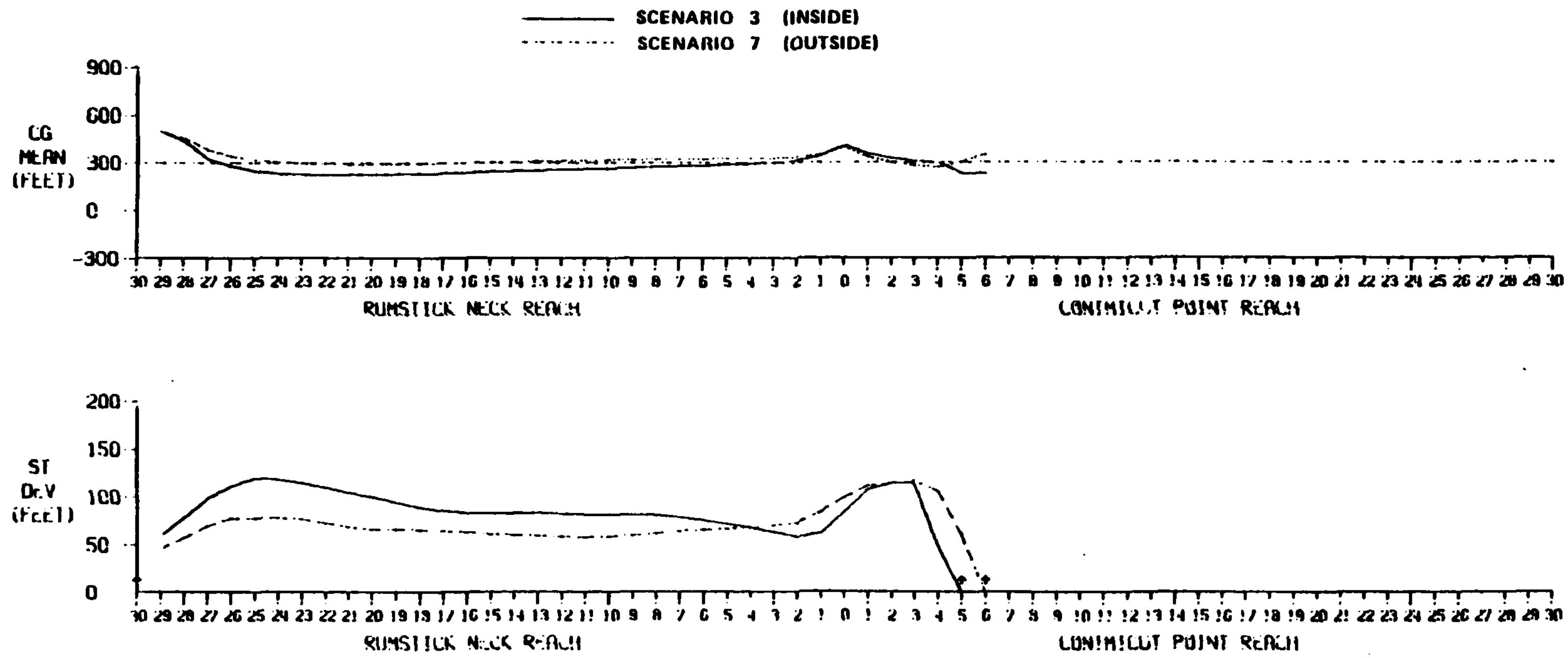
LIGHTED, STAGGERED OUTSIDE



STAGGERED INSIDE VS. AS IS
NIGHT

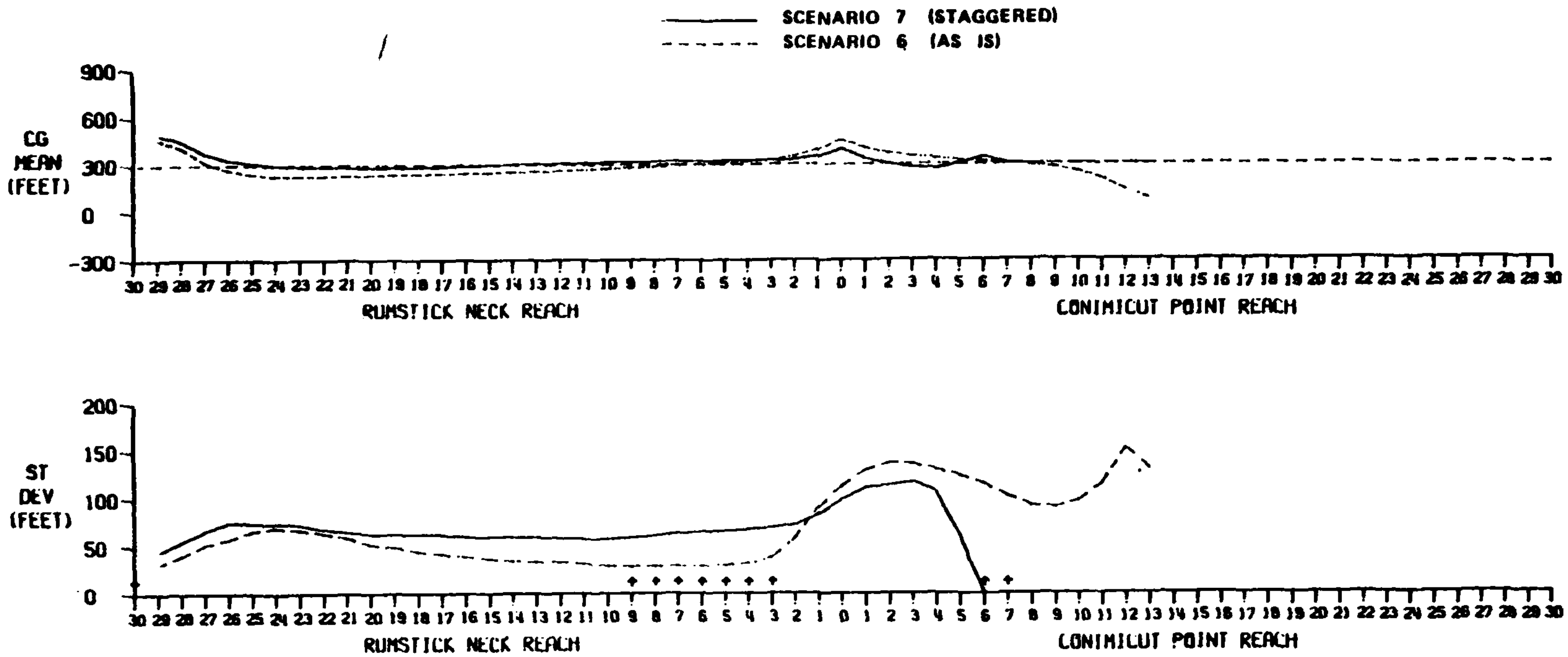


STAGGERED INSIDE VS. STAGGERED OUTSIDE
NIGHT



STAGGERED OUTSIDE VS. AS IS

NIGHT



Appendix C
THE RELATIVE RISK FACTOR (RRF)

C.1 QUANTIFICATION OF THE RISK OF AN ACCIDENT

A very basic assumption of the program is that there exists a dependent relationship between the risk of accidents and the aid to navigation system. The better the aid system design, the lower the risk of accidents. The relationships of aids to the pilot's ability to stay inside the channel and avoid a grounding accident is most obviously related to the aids and is continuous throughout a transit in restricted waterways. But it is assumed that the design of aid systems, by the same principles, is also related to other types of accidents: that is, collisions and rammings. The pilot's ability to avoid accidents (collisions, rammings, and groundings) depends (not entirely, of course) on the aid system and its effectiveness in enabling him to make accurate and timely judgments of his position, velocity, and acceleration. In avoiding groundings, he must be able to make these judgments relative to the edges of the channel. In this process, the channel edge itself is not visible and the aid system (whether visual aids, radar, radio aids, or some combination) is all he has. In avoiding collisions and rammings the pilot must make his judgments relative to some moving or fixed object. The object to be avoided serves the function of an aid, but is not sufficient under all conditions in restricted waterways. An aid system that helps the pilot to determine his status contributes to his ability to avoid any type of accident.

Quantification of this relationship has previously been difficult due to the low occurrence of accidents relative to the number of transits (typically one accident for every 10,000 transits). Additionally, accident statistics could not be related to aid system designs because of the large number of factors contributing to the accident, such as human error, equipment failure, visibility, light, traffic, etc.

The aids to navigation project has provided a set of piloting performance data which can be used to provide a "relative" indication of the risk of an accident as a function of aid system design. This data was compiled on a shiphandling simulator designed specifically to quantify the relationships between aid system designs and the risk of accidents. The "relative" characteristic of this data must be stressed in that the data are indicative of the differences in the risk of accidents as a function of alternate aid system design characteristics. Too few samples were run on the simulator to attempt to predict occurrences on the order of one every 10,000 transits.

The measure derived to quantify the relative risk of accidents is the "relative risk factor." This factor represents an estimate of the probability that a portion of the ship will cross a channel edge. It is based on an assumption that ship tracks are normally distributed about a mean track. It is suggested that the relative risk factor is directly proportional to the probability of grounding and that changes in the relative risk factor are proportional to changes in the actual probability of grounding:

$$RRF = (K)(PG) \qquad (C-1)$$

where:

RRF: relative risk factor
PG: probability of grounding
K: correction factor

Given these assumptions if the relative risk factor is increased by a multiple of 10 with increased buoy spacing, then it is assumed the actual probability of grounding will be increased by a multiple of 10 also.

The relative risk factor, although not a direct measure of the probability of an accident, can be satisfactorily applied to the design of aid systems when one design is being compared to another. Designs which achieve a minimum relative risk factor can be assumed to provide the maximum safety possible relative to other designs. Designs which achieve relative risk factors equivalent to those for existing channels can be assumed to exhibit the same safety record as the existing channel under similar environmental conditions.

C.2 DERIVATION OF THE RELATIVE RISK FACTOR (RRF)

The relative risk factor (RRF) is taken to be the sum of the probabilities that the port or the starboard extreme points of the ship will exceed the channel edge during a transit. These probabilities are calculated on the assumption that ship tracks will be normally distributed to either side of a mean track in accordance with the standard deviation of the ship's track. Data defining the mean track and the standard deviation of the tracks as a function of aids to navigation system design are taken from experiments conducted on the ship simulator.

The probabilities required are derived by determining the number of standard deviations which lie between the extreme points of the ship and the channel boundary and then calculating the area under the normal distribution curve beyond this point. These calculations are made when the ship is properly oriented to account for the mean crosstrack displacement of the ship's center of gravity (CG) and the required crab angle (CA) due to a crosscurrent component. These relationships are shown in Figure C-1. The areas under normal distribution curves which fall beyond the channel edge are shown in Figure C-2. The relative risk factor is the sum of these two areas.

$$RRF = PS + PP \qquad (C-2)$$

where:

PS: probability the extreme starboard point will cross the starboard channel edge
PP: probability the extreme port point will cross the port channel edge

The values for the RRF are judged to be conservative estimates of the probability of grounding. That is, if they are biased, they are biased in a safe or cautious direction: in this case, they may be larger than they should be and may overestimate the risk. There are a number of reasons why any bias here is in a conservative direction. The first is the assumption of normal distribution. The standard deviations and mean displacement values were derived based on a piloting strategy of staying on the channel centerline. There is evidence that when pilots intentionally maneuver close to the channel edge (e.g., when passing traffic ships on setting up for a turn), they reduce the variability of ship's tracks (standard deviation). Therefore, the distribution is not likely to be normal when the ship is near the channel edge. The data are presently not sufficient to determine the exact distribution, so the assumption of the normal distribution is made as a conservative one. Given that conservative estimates of the RRF are used, and given that proportional relationships between the RRF and the actual probability of grounding are assumed; these values are also conservative estimates of the actual probability of grounding.

The second reason the relative risk factor may be conservative is that most grounding hazards do not exist at the exact edge of the channel. In fact, in many areas a ship may exceed channel edges safely with the grounding hazard being only an occasional shoal. Correction for such phenomenon may be made by using the width of navigable water rather than the channel width for calculating RRF.

. A third reason the RRF may be conservative is the beneficial influence of bank effects. Hydrodynamic forces on a ship's hull near a bank will act to repel the ship from the bank with no control input from the pilot. The main body of performance data does not presently account for this effect.

Although the above considerations prohibit the strict interpretation of the relative risk factor as the probability of grounding, it is seen that in all cases the relative risk factor is a conservative indicator of the probability of grounding. Thus, the RRF contains a built-in safety factor when it is used in a design context. This safety factor is likely beneficial since it allows for a variety of piloting contingencies to be accommodated (e.g., unseasonable tidal currents, piloting errors, passing ship hydrodynamic effects, operation of ships larger than the norm, excessive winds, very limited visibility, unique bottom contours).

C.3 CALCULATION OF THE RELATIVE RISK FACTOR (RRF)

The calculation of the RRF begins with the selection of baseline values for the mean crosstrack displacement (MN) and the crosstrack standard deviation (SD) for each region. These values are selected from simulator data and are dependent on the aid configuration and the environmental conditions. The baseline values of MN and SD are adjusted for the ship size, and channel width of the candidate channel. The adjusted values, MN' and SD', are used together with the ship and channel dimensions to calculate the probabilities of the ship's hull crossing either edge of the channel. The relative risk factor is calculated as the sum of these probabilities.

The adjusted mean and standard deviations are calculated as the product of the baseline values times correction factors associated with ship's size and channel width. Equations C-3 and C-4 indicate the calculations which must be made for each region:

$$MN' = (MN)(SHP)(MCWID) \qquad (C-3)$$

$$SD' = (SD)(SHP)(SCWID) \qquad (C-4)$$

where:

- MN: Baseline mean crosstrack position (feet)
- SD: Baseline crosstrack standard deviation (feet)
- MCSHP: Mean correction factor for ship size
- MCWID: Mean correction factor for channel width
- SCSHP: Standard deviation correction factor for ship size
- SCWID: Standard deviation correction factor for channel width

The probabilities of the ship's hull crossing the channel edges are calculated based on the number of adjusted standard deviations which fall between the ship's extreme points and the channel edges. The adjusted beam, B', is calculated with the pivot at the center of the ship for simplicity. Equations C-5, C-6, and C-7 indicate the calculations required to determine these multiples:

$$B'/2 = (L/2)(VX/VMIN) + (B/2) \qquad (C-5)$$

$$NS = [(W/2) - (MN') - (B'/2)]/(SD') \qquad (C-6)$$

$$NP = [(W/2) + (MN') - (B'/2)]/(SD') \qquad (C-7)$$

where:

- B'/2: Ship's beam adjusted for crab angle (feet)/2
- L: Ship's length (feet)
- VX: Cross channel component of current (knots)
- VMIN: Ship's minimum transit speed (knots)
- B: Ship's beam (feet)

and

- NS: Number of SD' between the extreme starboard point of the ship's hull and the starboard channel edge (may be negative)
- NP: Number of SD' between the extreme port point of the ship's hull and the port channel edge (may be negative)
- W: Channel width (feet)

The probabilities of crossing the port and starboard edges of the channel are calculated based on the equations for the normal probability distribution. The probabilities can be obtained using the values provided

in a table in the SRA Design Manual. The relative risk factor is calculated as the sum of the probabilities (equation C-2).

$$RRF = PS + PP \qquad (C-2)$$

where:

PS: Probability of the extreme starboard point of the ship's hull crossing the starboard channel edge. Assumes a normal distribution of the tracks.

PP: Probability of the extreme port point of the ship's hull crossinq the port channel edge. Assumes a normal distribution of tracks.

RRF: Relative risk factor

A sample calculation appears in Figure C-3.

RELATIVE RISK FACTOR CALCULATION SHEET

CHANNEL IDENTIFICATION

1. Channel name and location Narragansett Bay

2. Chart no. 13224   3. Latitude, longitude of midpoint ______

CHANNEL AND ENVIRONMENTAL PARAMETERS

4. Channel width in feet — 500 ft

5. Maximum crosscurrent component in knots — 0.25 kts

6. Maximum wind velocity in knots — ______ kts

DESIGN VESSEL PARAMETERS

7. Ship type tanker — dead weight tonnage 30,000 dwt

8. Minimum expected transit speed in knots — 6 kts

9. Maximum expected transit speed in knots — – kts

10. Ship length in feet — 570 kt

11. Ship beam in feet — 95 kt

DESIGN PARAMETERS (CIRCLE ONE)

12. AN detection distance: less than AN spacing (radar) — greater than AN spacing (visual)

13. Daylight conditions: day — night/dusk/dawn

14. AN configuration: gated low sens range — staggered low sens range — one-side

15. AN spacing: 5/8 nm — 1 nm — 1-1/4 nm

16. Maximum expected crab angle

$$TAN^{-1} \times \frac{\text{line 5}}{\text{line 8}} \quad TAN^{-1}\left(\frac{0.25}{6}\right) = \underline{\;2.39\;} \text{ deg}$$

Figure C-3

CALCULATED ADJUSTED MEAN AND STANDARD DEVIATION

17. Baseline MN x MN ship correction factor x MN width correction factor = adjusted MN

97 ft x 1 x 1 = 97 ft

18. Baseline SD x SD ship correction factor x SD width correction factor = adjusted SD

34 ft x 1 x 1 = 34 ft

CALCULATED ADJUSTED BEAM/2

19. $\frac{\text{Ship length (line 10)}}{2}$ $\frac{\text{crosstrack current velocity (line 5)}}{\text{minimum expected speed (line 8)}}$

$\frac{\text{ship's beam (line 11)}}{2}$ = adjusted beam/2

(590 /2 x 0.2516) + 85 /2 = 54.79 ft

CALCULATE THE RELATIVE RISK FACTOR

20. $\left(\frac{\text{channel width (line 4)}}{2} - \text{adjusted mean (line 17)} - \text{adjusted beam/2 (line 19)}\right) / \text{adjusted SD (line 18)}$ = NS

(500 /2 - 97 - 54.79)/ 34 = 2.89

21. $\left(\frac{\text{channel width (line 4)}}{2} + \text{adjusted mean (line 17)} - \text{adjusted beam/2 (line 19)}\right) / \text{adjusted SD (line 18)}$ = NP

(500 /2 + 97 - 54.79)/ 34 = 8.59

22. Value of NS from table + value of NP from table = RRF

0.0019 + 0.0000 = 0.0019

Figure C-3 (Continued)

Appendix D

AT-SEA TRACK PLOTS IN ORIGINAL NARRAGANSETT BAY

This appendix contains performance track plots of the at-sea data collected in the originally marked Narragansett Bay. Figure D-1 shows the location of the at-sea data collection. The at-sea data plotted shows performance for four daytime and four nighttime runs with tankers of approximately 30,000 dwt.

Table D-1 identifies the conditions represented by the track plots. The plots are grouped by day and night runs.

There are two types of track plots in this section. A combined plot is illustrated on page D-4. It consists of a series of three plots for one of the two channel legs. The axis for the abscissa is scaled so that one unit of alongtrack distance represents 475 feet (5/64 nm). The top plot displays the crosstrack mean and the middle plot displays the crosstrack standard deviation. The bottom plot is a combined plot showing the crosstrack mean and an envelope encompassing two standard deviations to either side, an area within which performance is expected to occur 95 percent of the time. A comparison plot is illustrated on page D-14. For each comparison there are two sets of axes, one showing the means of two conditions and one showing the crosstrack standard deviation as the performance measures. Data is plotted as a continuous unbroken line and a dotted line to distinguish the experimental conditions from each other.

Statistical tests were used to test the differences in performance at each data line, to determine if any differences between conditions were statistically significant. The means were compared using a t-test. The symbols along the axis of the mean plot indicate a difference at the 0.10 level of significance. The standard deviations were compared as variances using an F test. The symbols along the axis of the standard deviation plot also indicate a difference at the 0.10 level of significance.

Plot Notes:

1. On the plots, buoys and lights are positioned for the purpose of illustration and may not appear in their exact charted location.

2. Aids to Navigation symbols

   ◇ nun buoy

   ◆ can buoy

   red, lighted buoy

   black, lighted buoy

   light beacon

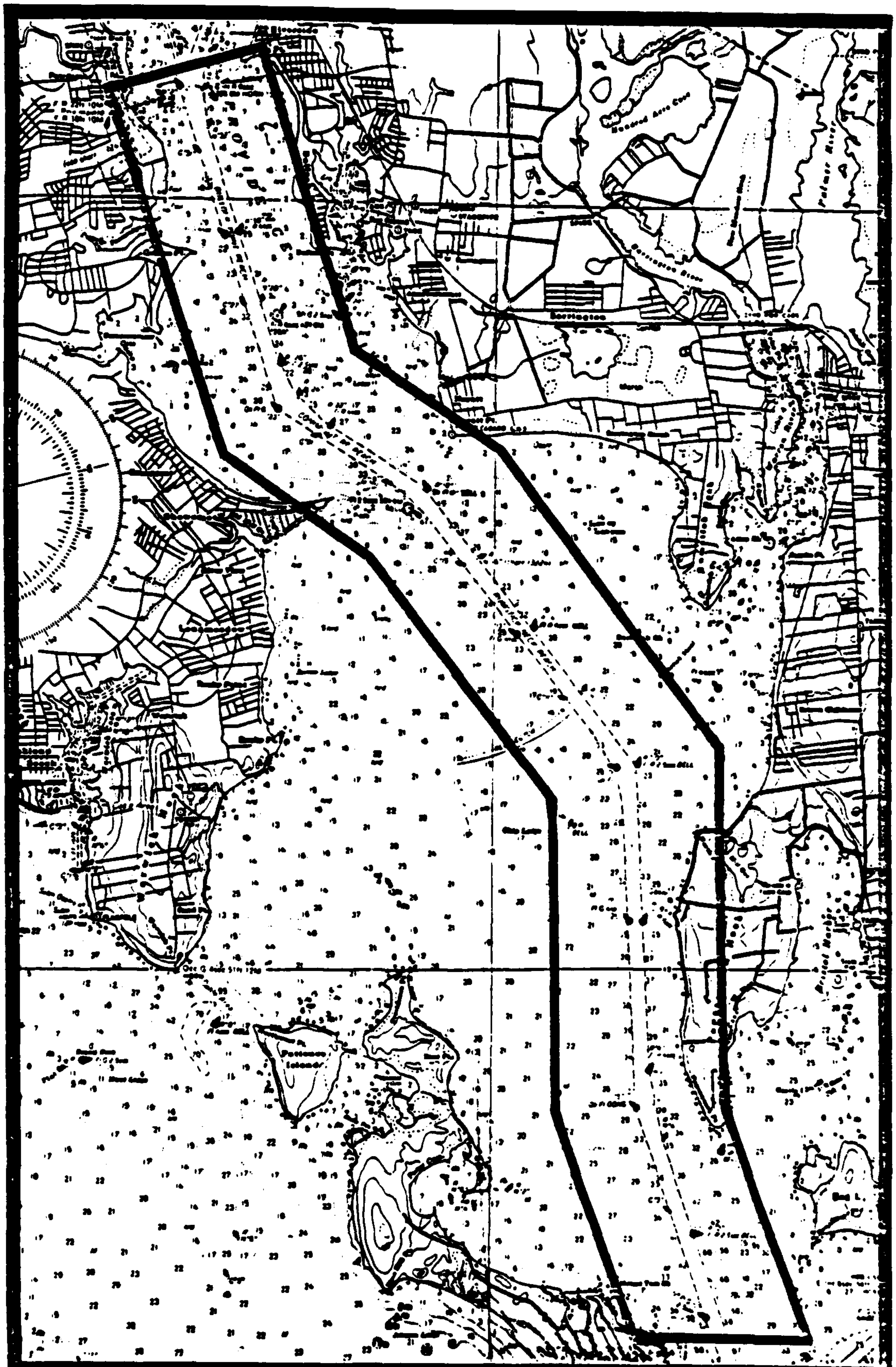


Figure D-1. Pre-aid Change Configuration in Upper Narragansett Bay (Chart 13221, March 28, 1981)

TABLE D-1. NARRAGANSETT BAY PRE-CHANGE AT-SEA TRANSITS

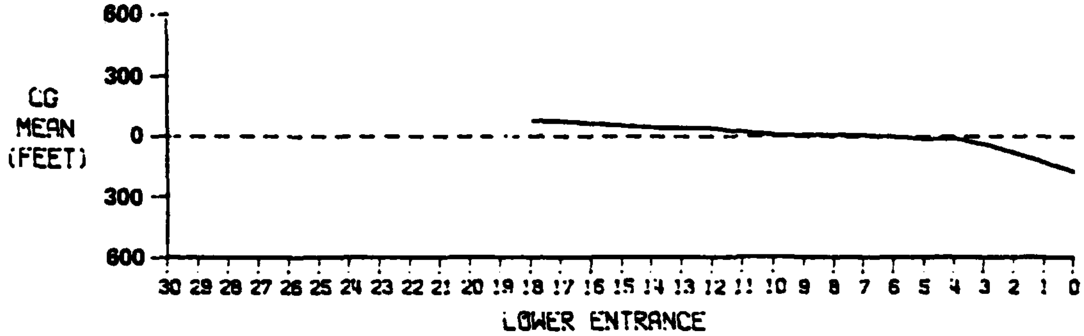
Page	Variable	Channel	Plot
D-4	Day	Lower Entrance	Combined
D-5	Day	Upper Entrance	Combined
D-6	Day	Rumstick Neck Reach	Combined
D-7	Day	Conimicut Point Reach	Combined
D-8	Day	Bullock Point Reach	Combined
D-9	Night	Lower Entrance	Combined
D-10	Night	Upper Entrance	Combined
D-11	Night	Rumstick Neck Reach	Combined
D-12	Night	Conimicut Point Reach	Combined
D-13	Night	Bullock Point Reach	Combined
D-14	Day/Night	Lower Entrance/ Upper Entrance	Comparison
D-15	Day/Night	Rumstick Neck Reach/ Conimicut Point Reach	Comparison
D-16	Day/Night	Bullock Point Reach	Comparison

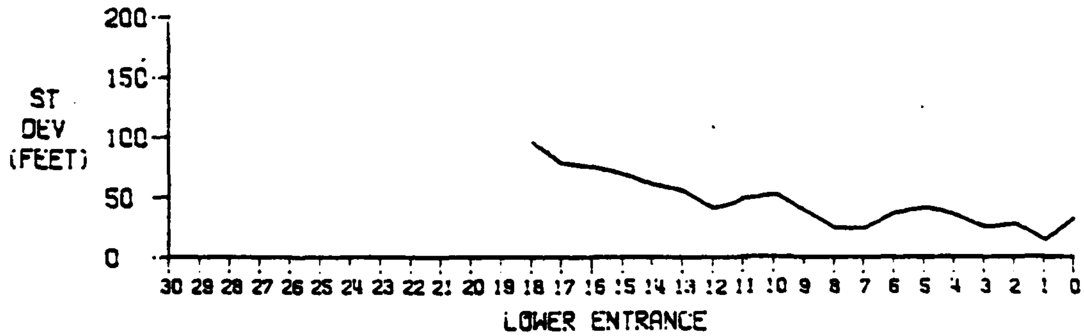
AT-SEA

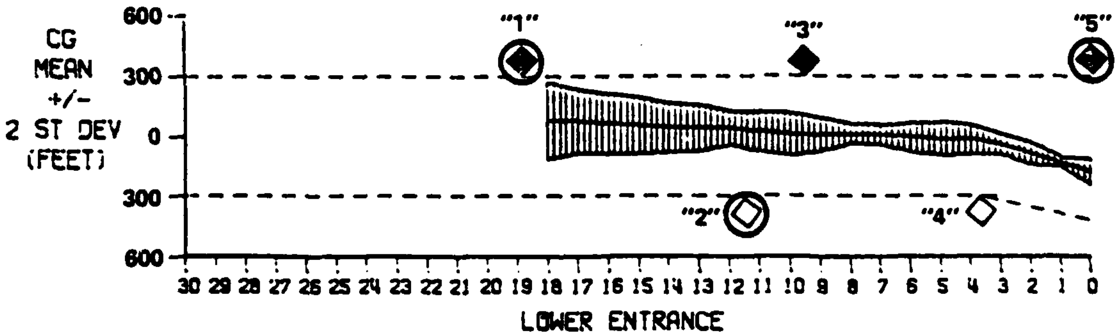
DAYTIME TRANSIT

NARRAGANSETT BAY

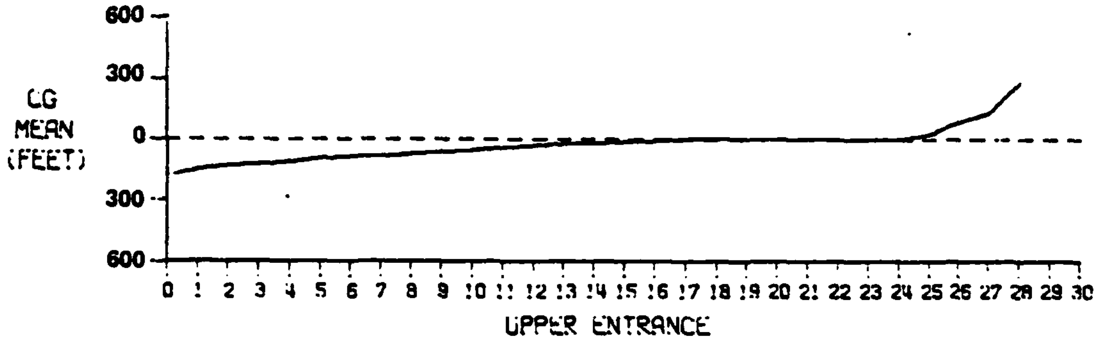
LOWER ENTRANCE CHANNEL

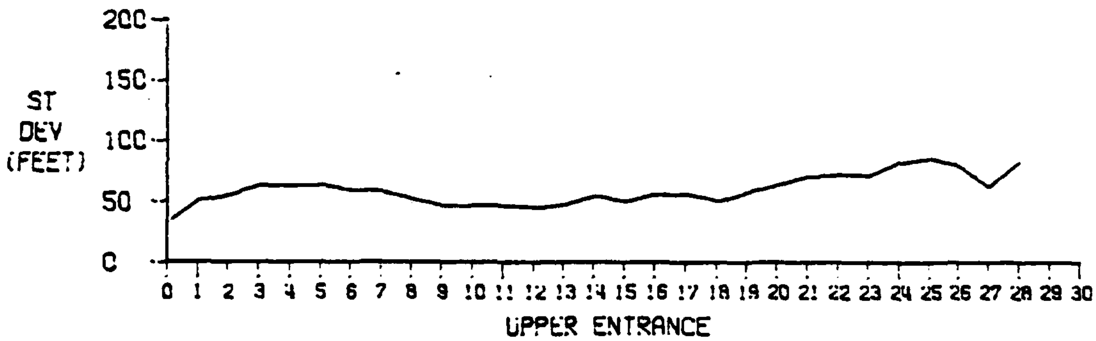


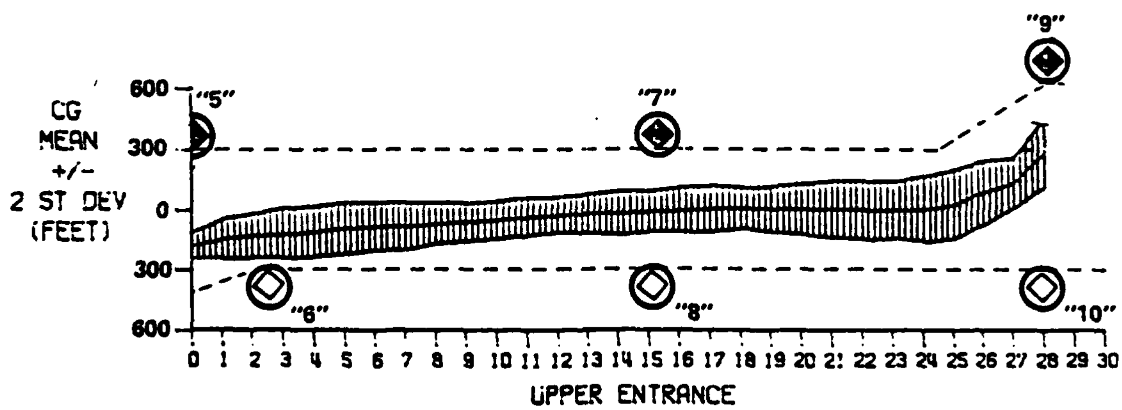




AT-SEA
DAYTIME TRANSIT
NARRAGANSETT BAY
UPPER ENTRANCE CHANNEL





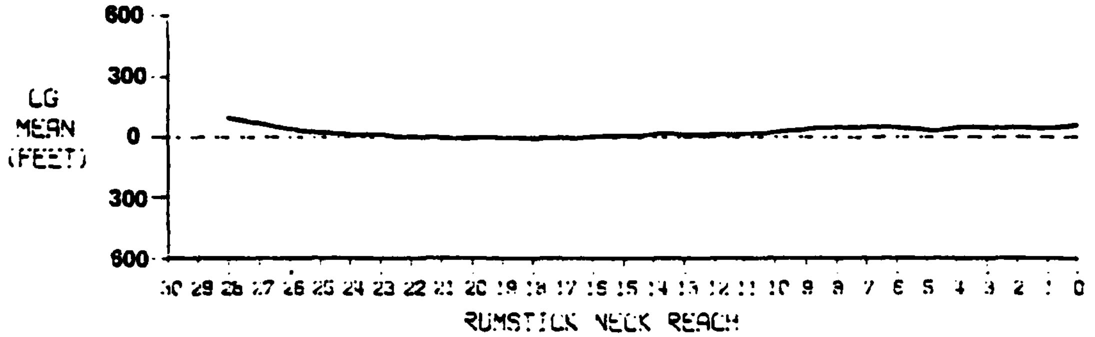


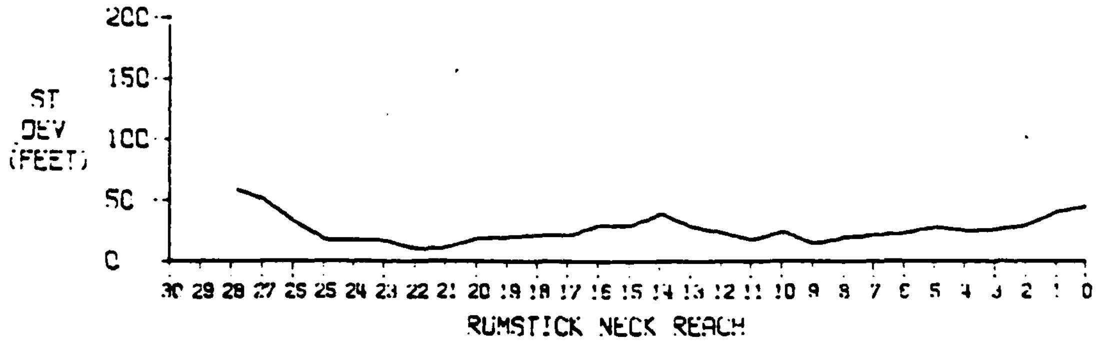
AT-SEA

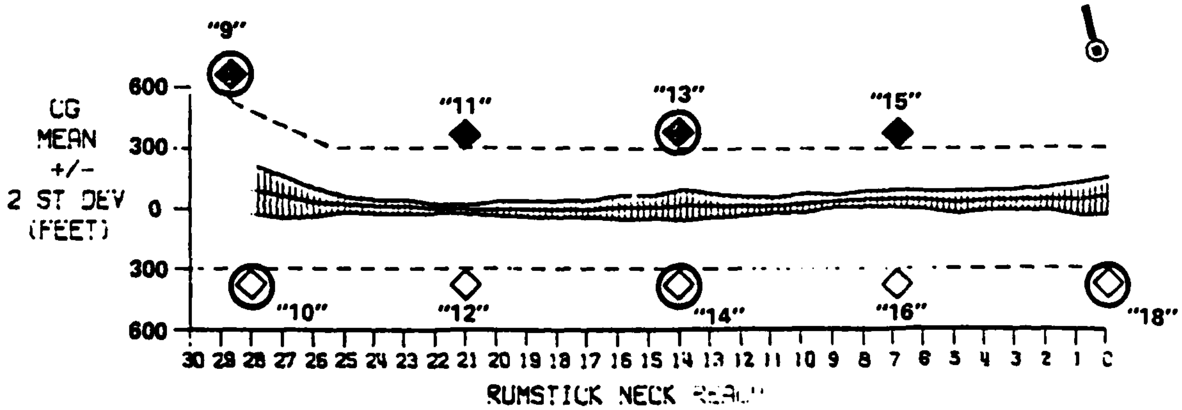
DAYTIME TRANSIT

NARRAGANSETT BAY

RUMSTICK NECK REACH





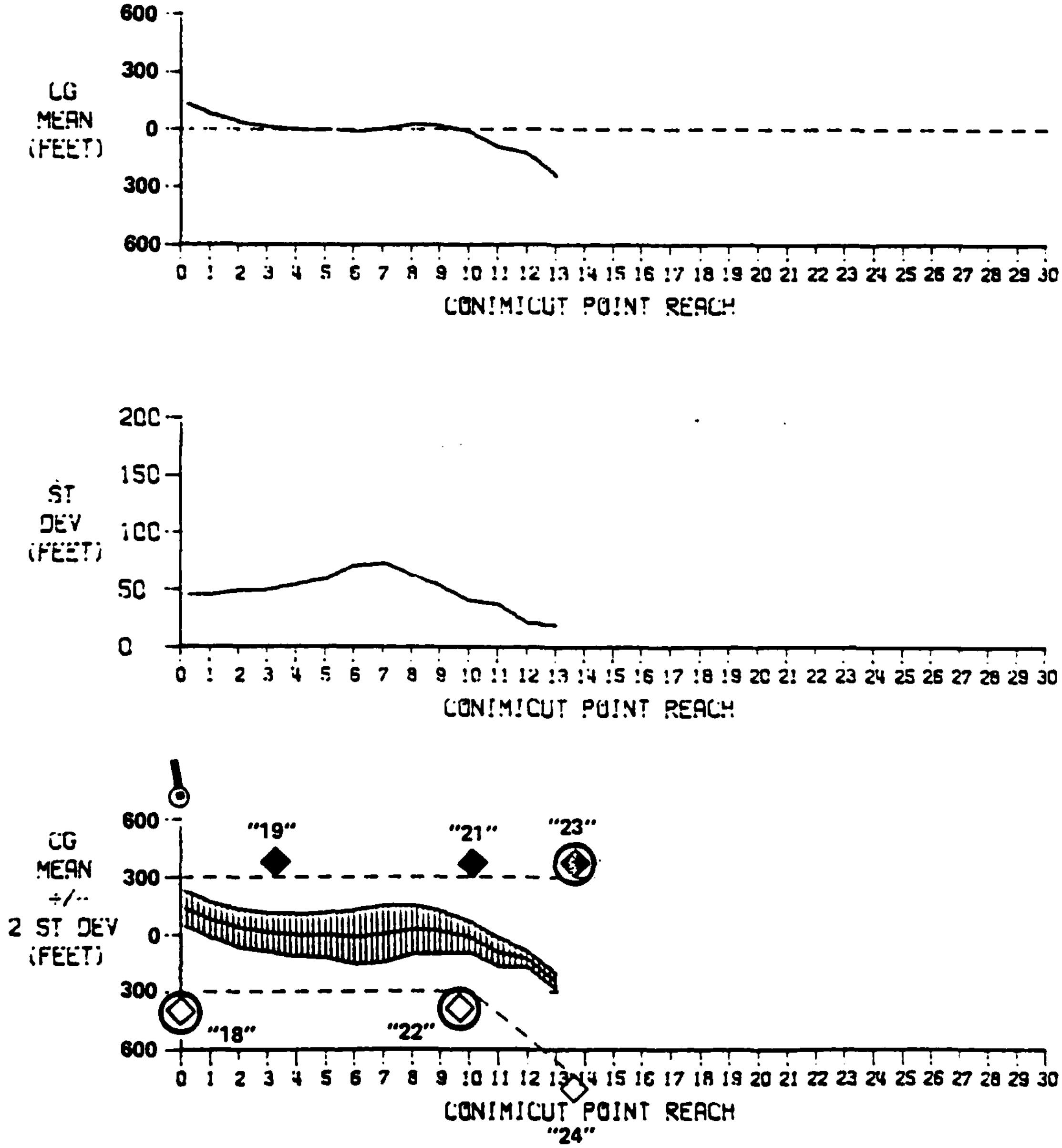


AT–SEA

DAYTIME TRANSIT

NARRAGANSETT BAY

CONIMICUT POINT REACH

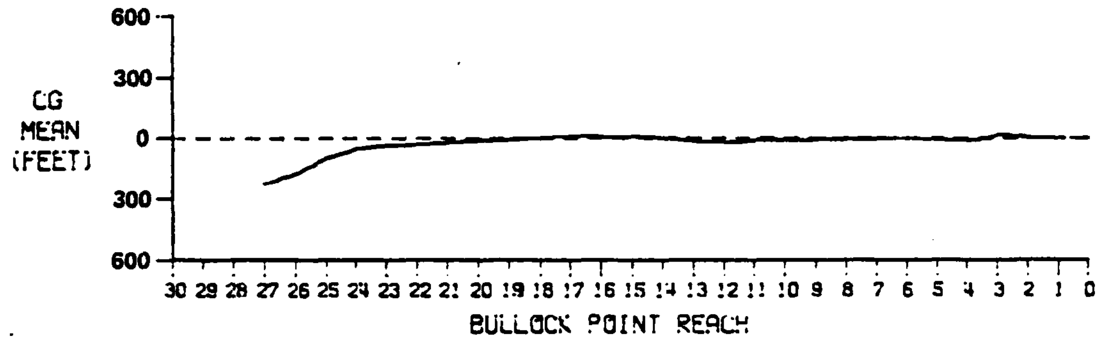


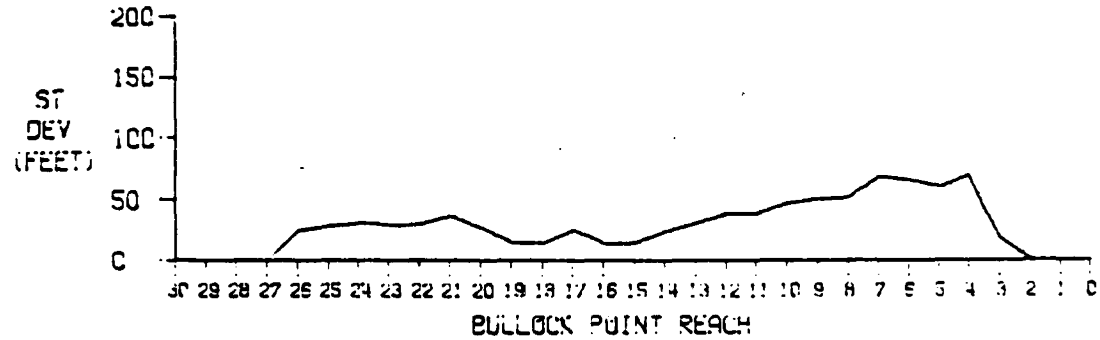
AT-SEA

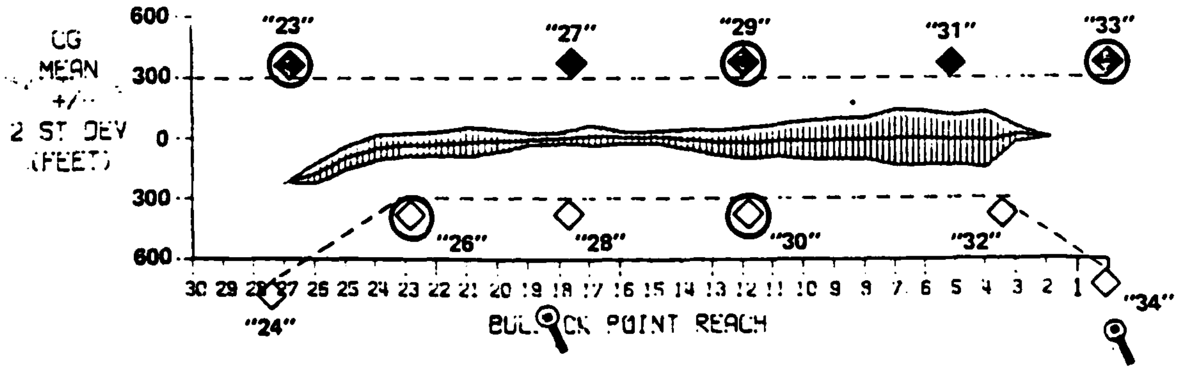
DAYTIME TRANSIT

NARRAGANSETT BAY

BULLOCK POINT REACH





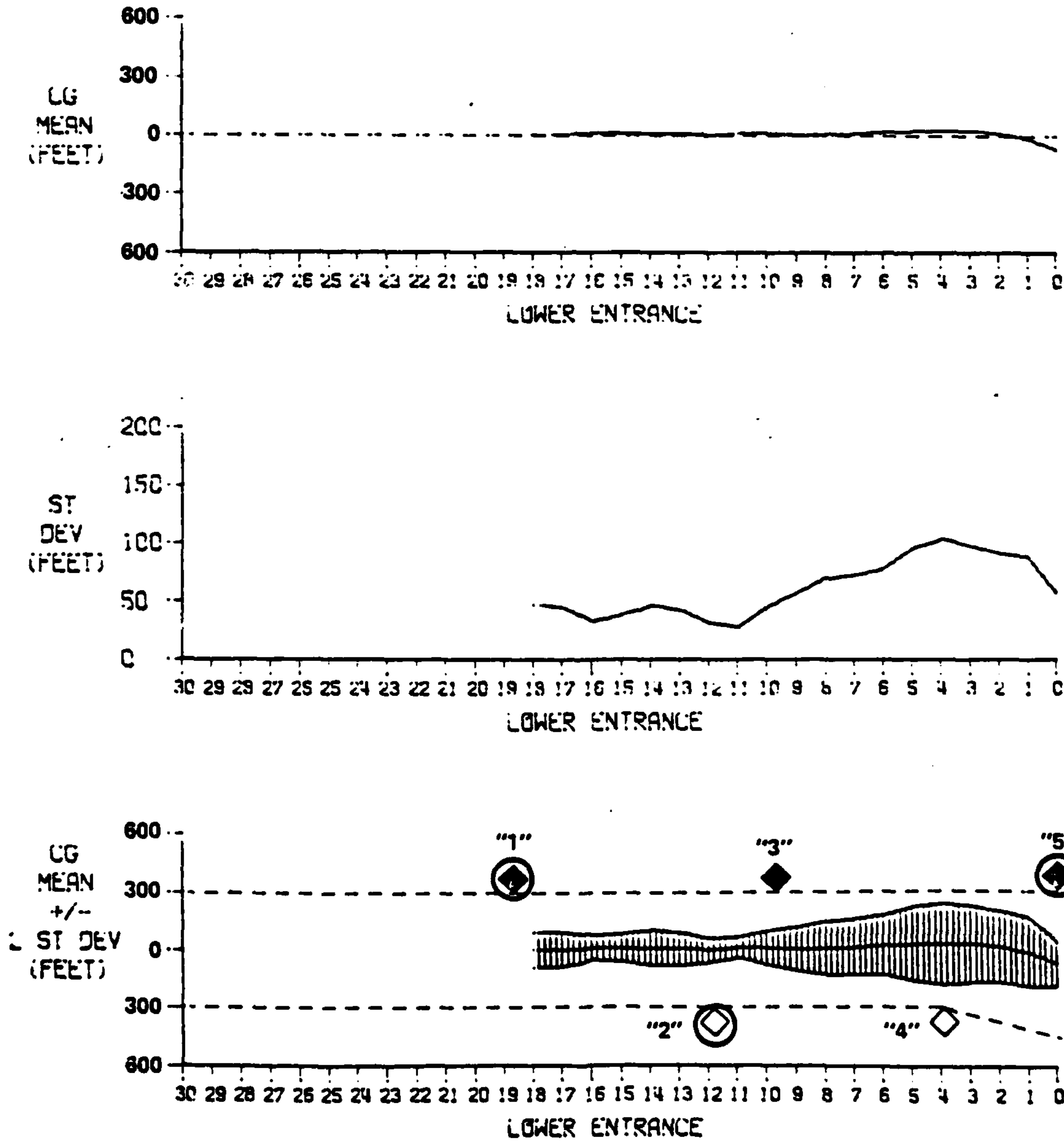


AT–SEA

NIGHTTIME TRANSIT

NARRAGANSETT BAY

LOWER ENTRANCE CHANNEL

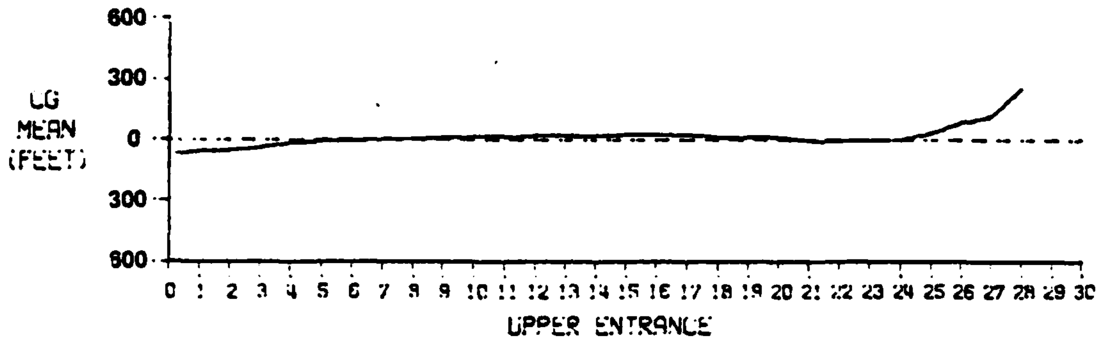


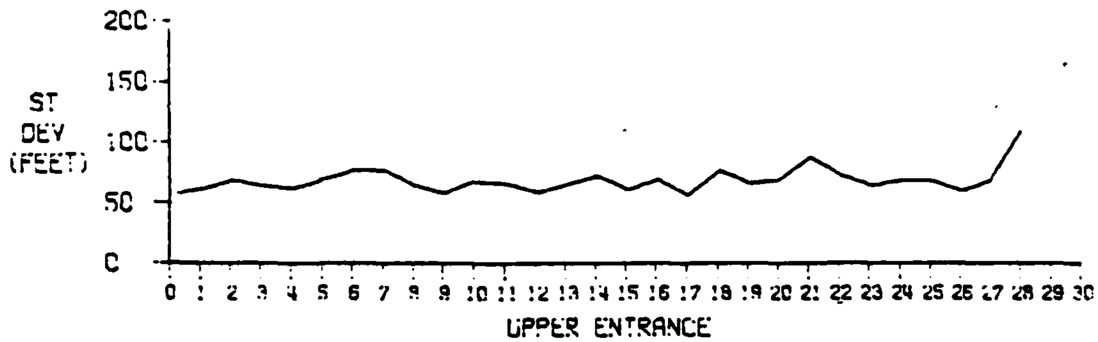
AT-SEA

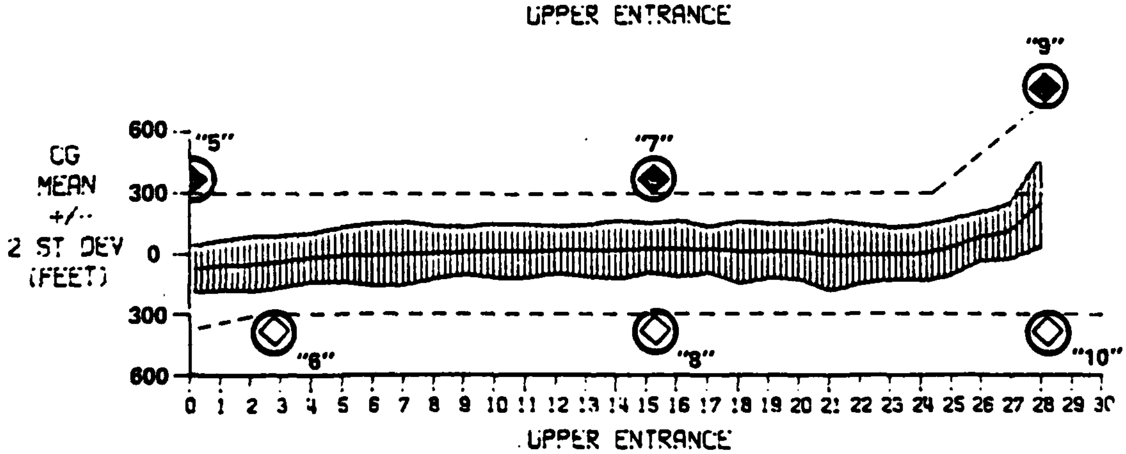
NIGHTTIME TRANSIT

NARRAGANSETT BAY

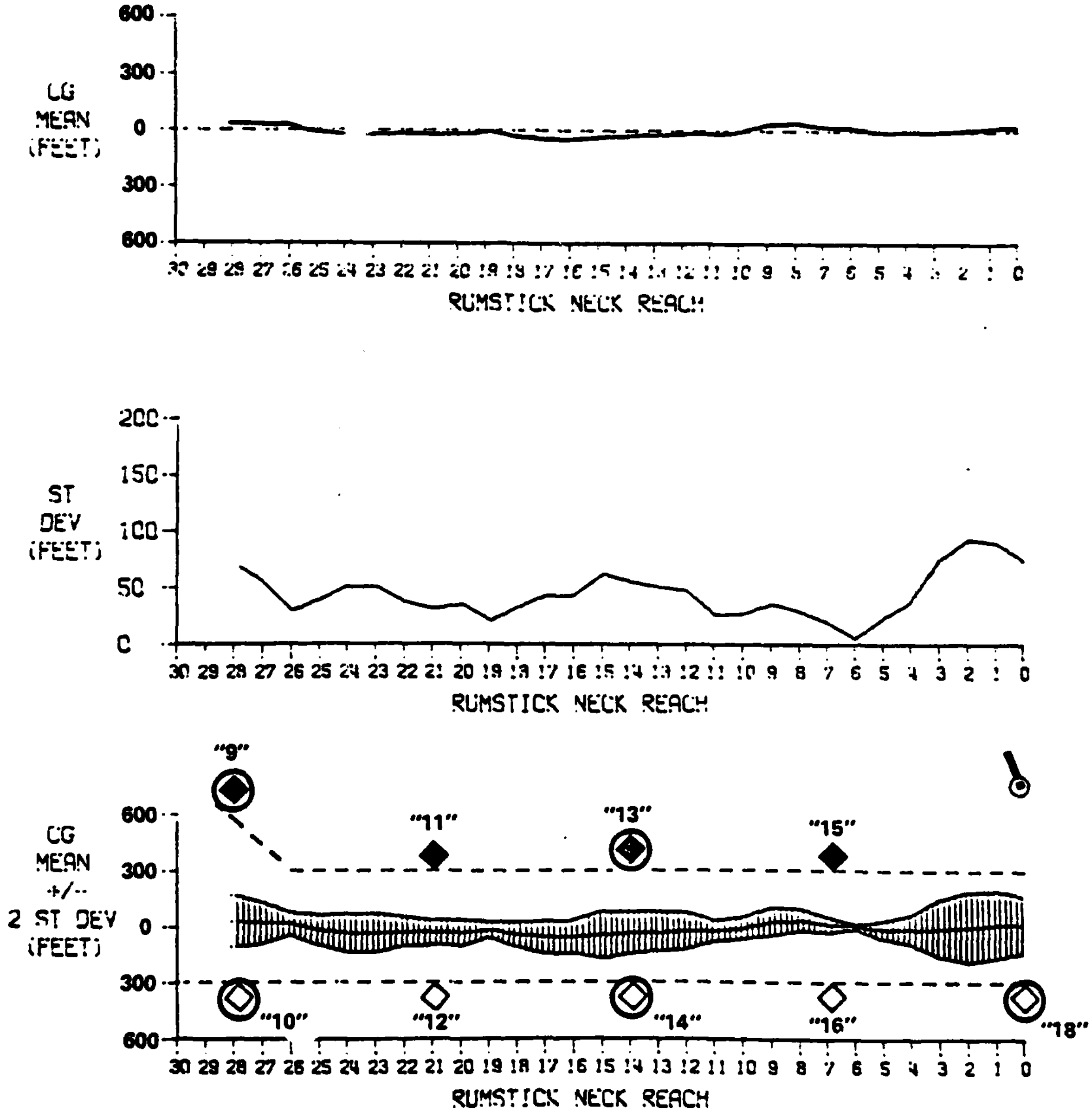
UPPER ENTRANCE CHANNEL







AT–SEA
NIGHTTIME TRANSIT
NARRAGANSETT BAY
RUMSTICK NECK REACH

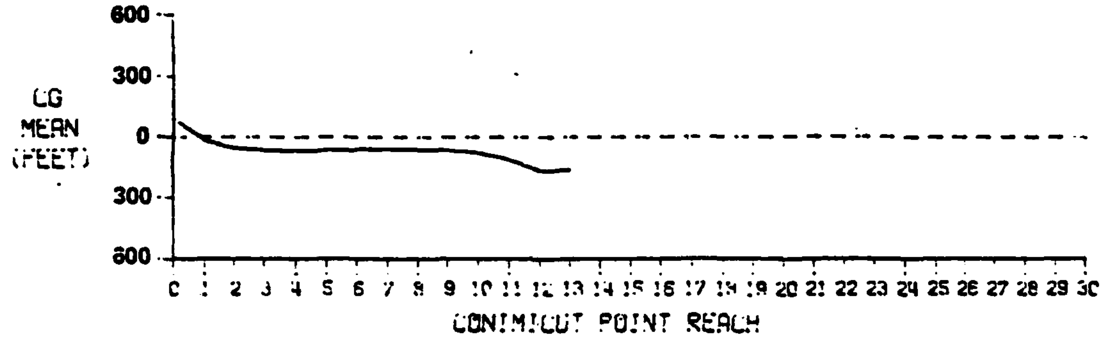


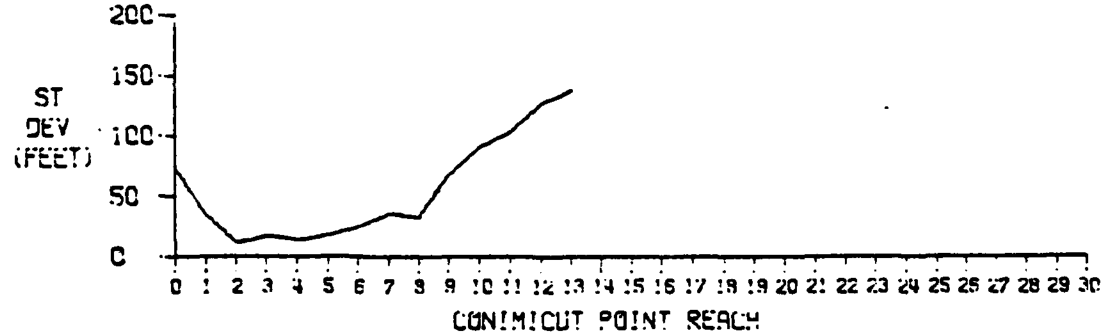
AT–SEA

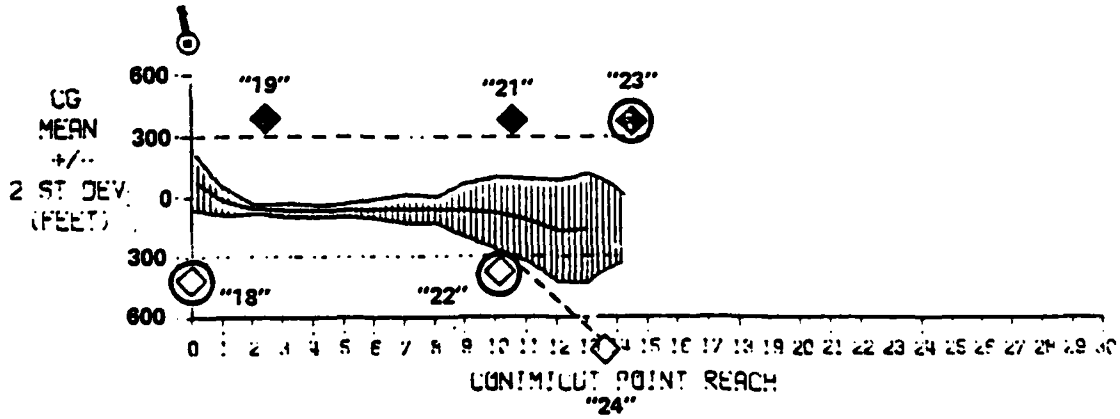
NIGHTTIME TRANSIT

NARRAGANSETT BAY

CONIMICUT POINT REACH





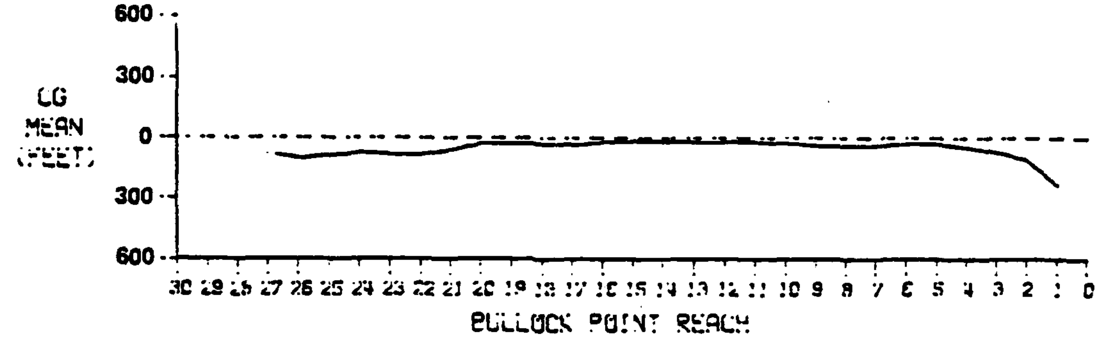


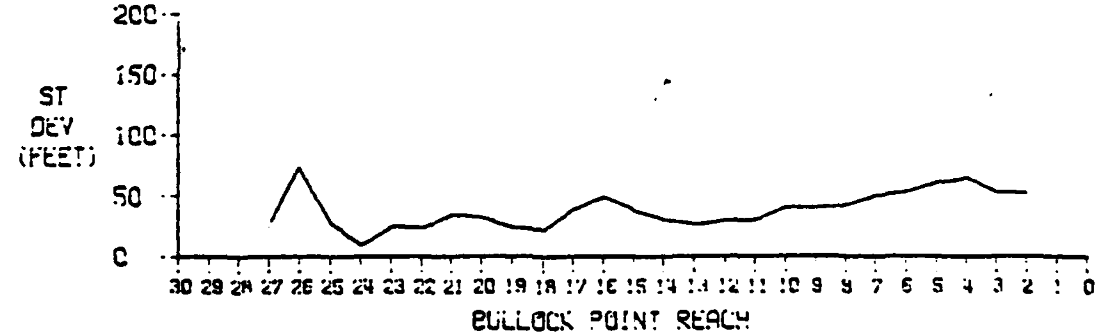
AT–SEA

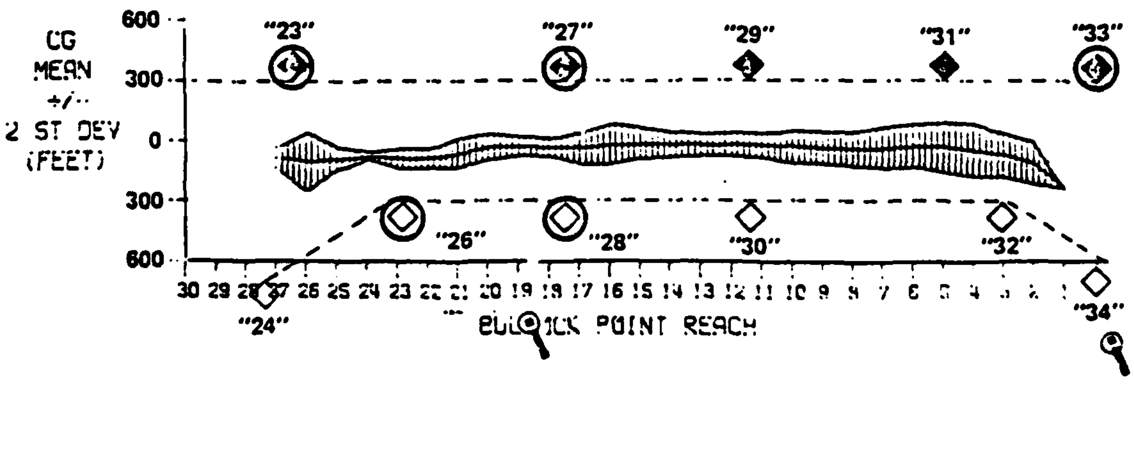
NIGHTTIME TRANSIT

NARRAGANSETT BAY

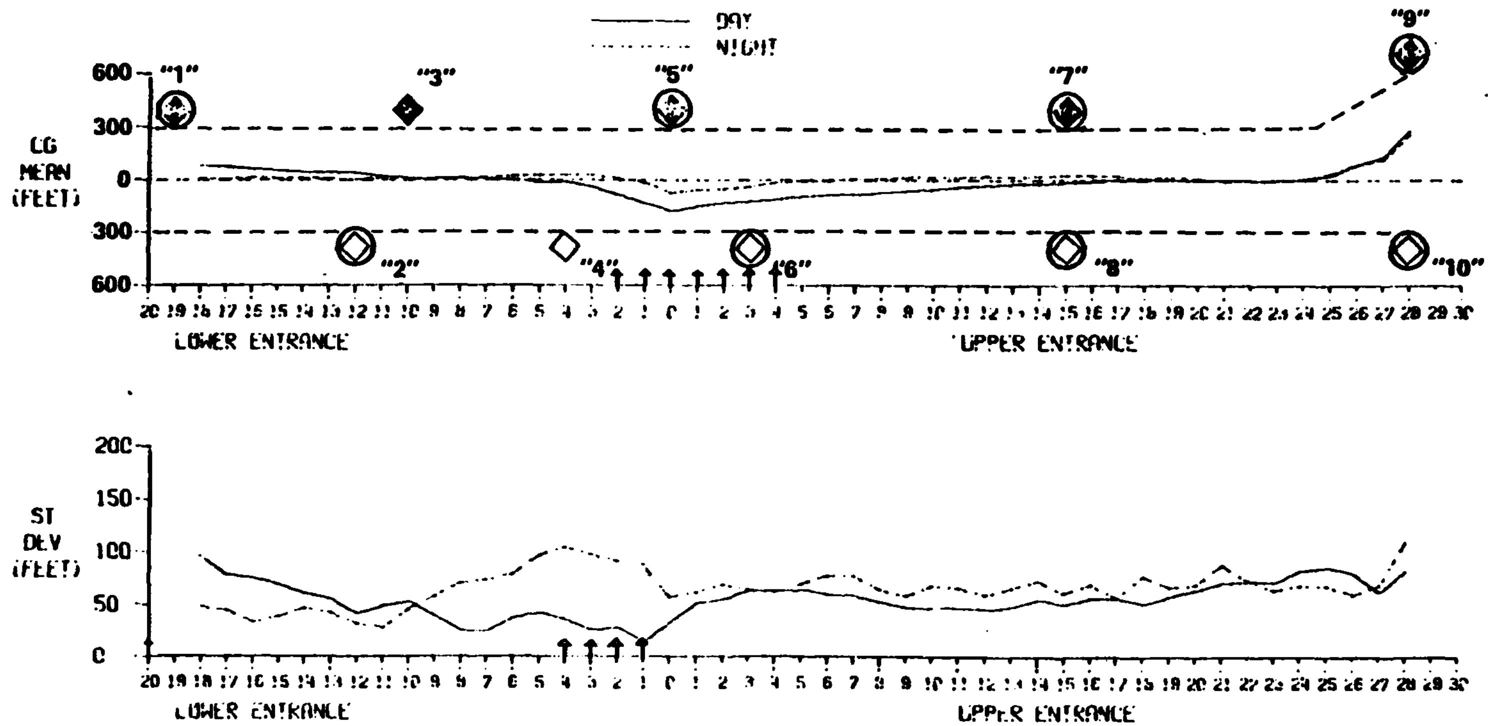
BULLOCK POINT REACH



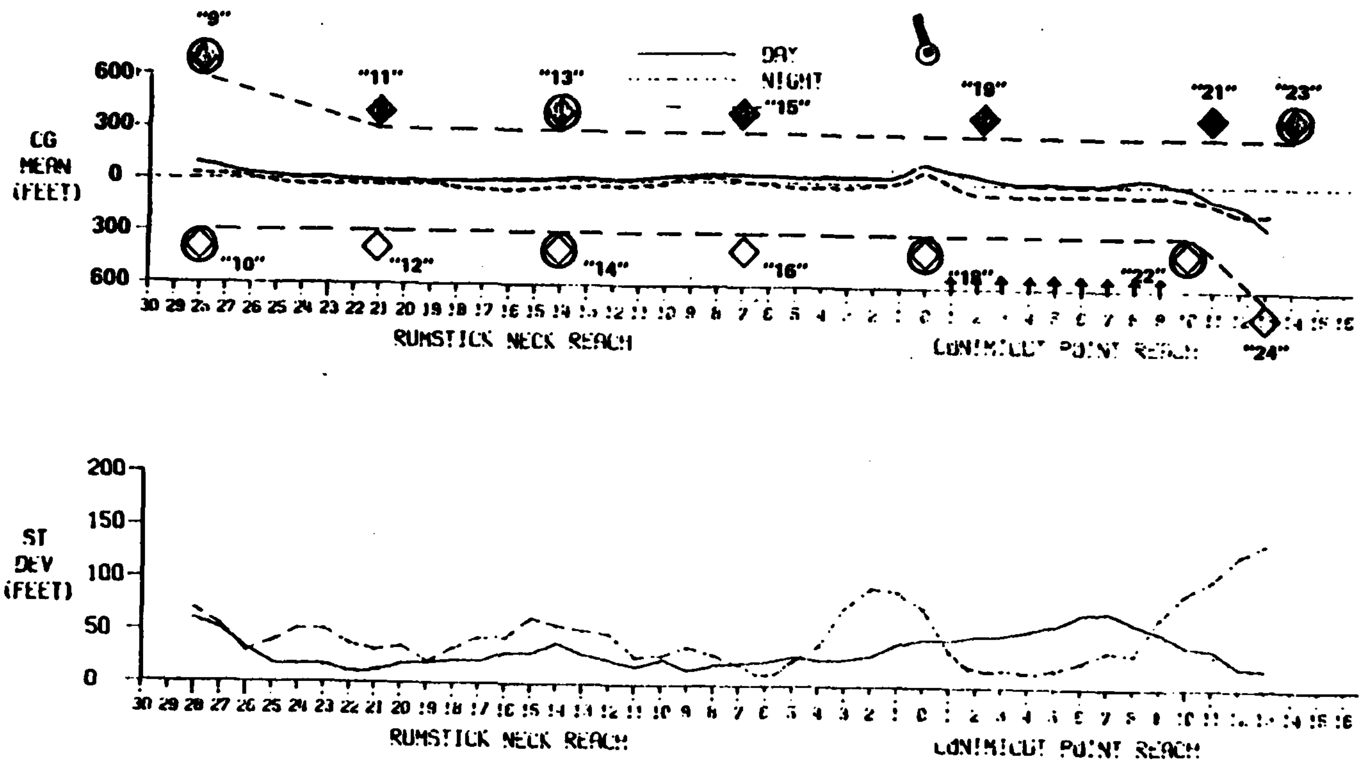




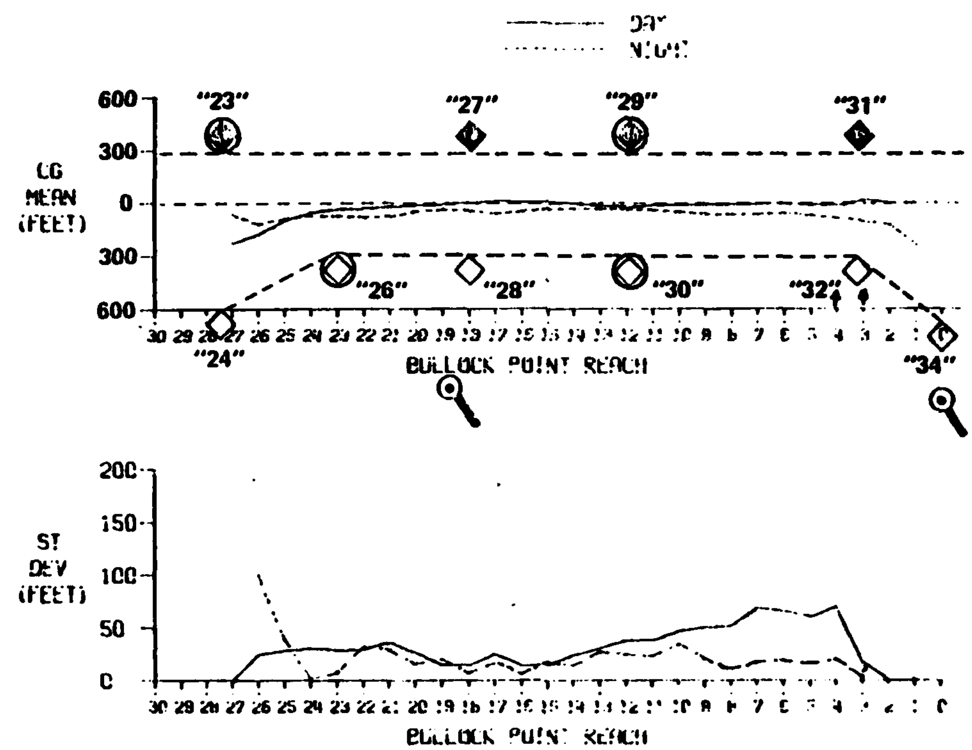
AT-SEA
NARRAGANSETT BAY
DAY/NIGHT COMPARISON.



AT-SEA
NARRAGANSETT BAY
DAY/NIGHT COMPARISON



AT–SEA
NARRAGANSETT BAY
DAY/NIGHT COMPARISON



Appendix E

AT-SEA TRACK PLOTS IN MODIFIED NARRAGANSETT BAY

This appendix contains performance track plots of the at-sea data collected in the modified Narragansett Bay. Figure E-1 shows the channels in which at-sea data was collected. The at-sea data plotted shows performance for two daytime runs and two nighttime runs with tankers of approximately 30,000 dwt.

Table E-1 identifies the conditions represented by the track plots. The plots are grouped by day and night runs.

A combined plot is illustrated on page E-4. It consists of a series of three plots for each of the channel legs. The axis for the abscissa is scaled so that one unit of alongtrack distance represents 476 feet (5/64 nm). The top plot displays the crosstrack mean and the middle plot displays the crosstrack standard deviation. The bottom plot is a combined plot showing the crosstrack mean and an envelope encompassing two standard deviations to either side, an area within which performance is expected to occur 95 percent of the time.

A comparison plot as illustrated on page E-19. For each comparison there are two sets of axes, one showing the mean and one showing the crosstrack standard deviation as the performance measures. Data is plotted as a continuous unbroken line and a dotted line to distinguish the day and night conditions.

Plot Notes:

1. On the plots, buoys and lights are positioned for the purpose of illustration and may not appear in their exact charted location.

2. Aids to Navigation symbols

   ◇ nun buoy

   ◆ can buoy

   red, lighted buoy

   black, lighted buoy

   lighted beacon

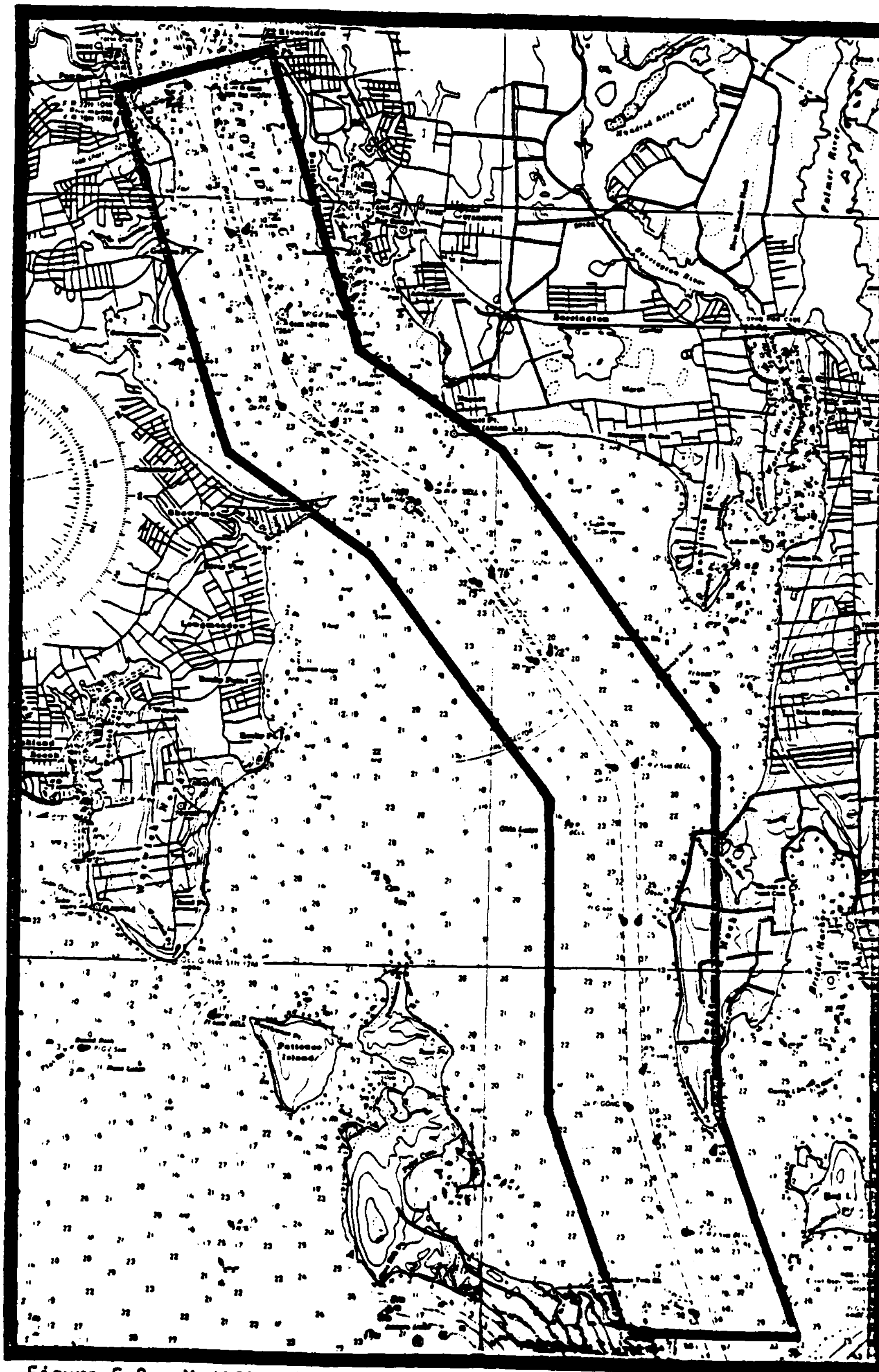
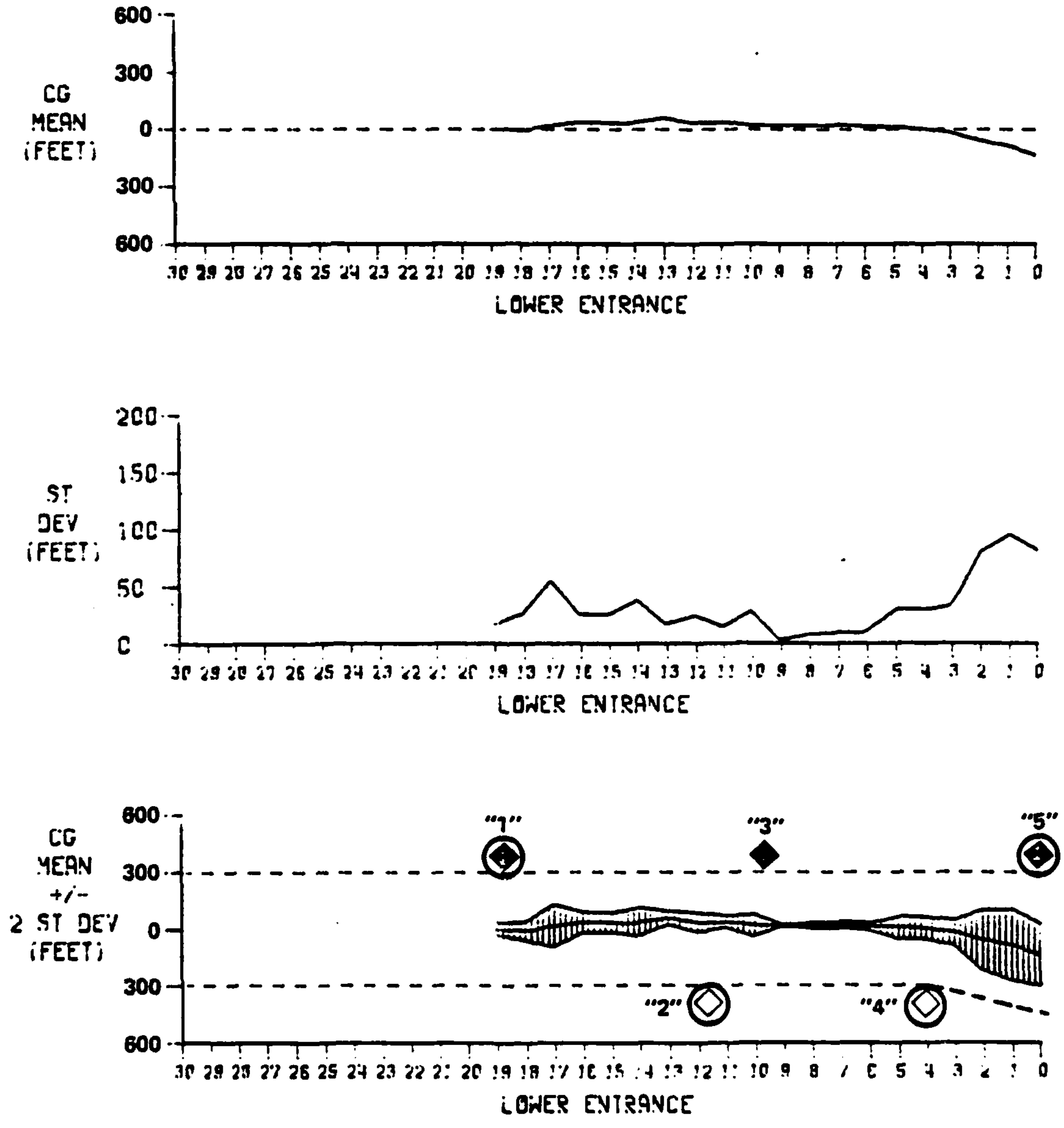


Figure E-2. Modified Aid Configuration in Upper Narragansett Bay

TABLE E-1. NARRAGANSETT BAY POST-AID CHANGE AT-SEA TRANSITS

Page	Variable	Channel	Plot
E-4	Day	Lower Entrance	Combined
E-5	Day	Upper Entrance	Combined
E-6	Day	Rumstick Neck Reach	Combined
E-7	Day	Conimicut Point Reach	Combined
E-8	Day	Bullock Point Reach	Combined
E-9	Night	Lower Entrance	Combined
E-10	Night	Upper Entrance	Combined
E-11	Night	Rumstick Neck Reach	Combined
E-12	Night	Conimicut Point Reach	Combined
E-13	Night	Bullock Point Reach	Combined
E-14	All Runs	Lower Entrance	Combined
E-15	All Runs	Upper Entrance	Combined
E-16	All Runs	Rumstick Neck Reach	Combined
E-17	All Runs	Conimicut Point Reach	Combined
E-18	All Runs	Bullock Point Reach	Combined
E-19	Day/Night	Lower Entrance	Comparison
E-20	Day/Night	Upper Entrance	Comparison
E-21	Day/Night	Rumstick Neck Reach	Comparison
E-22	Day/Night	Conimicut Point Reach	Comparison
E-23	Day/Night	Bullock Point Reach	Comparison

POST-CHANGE DAY



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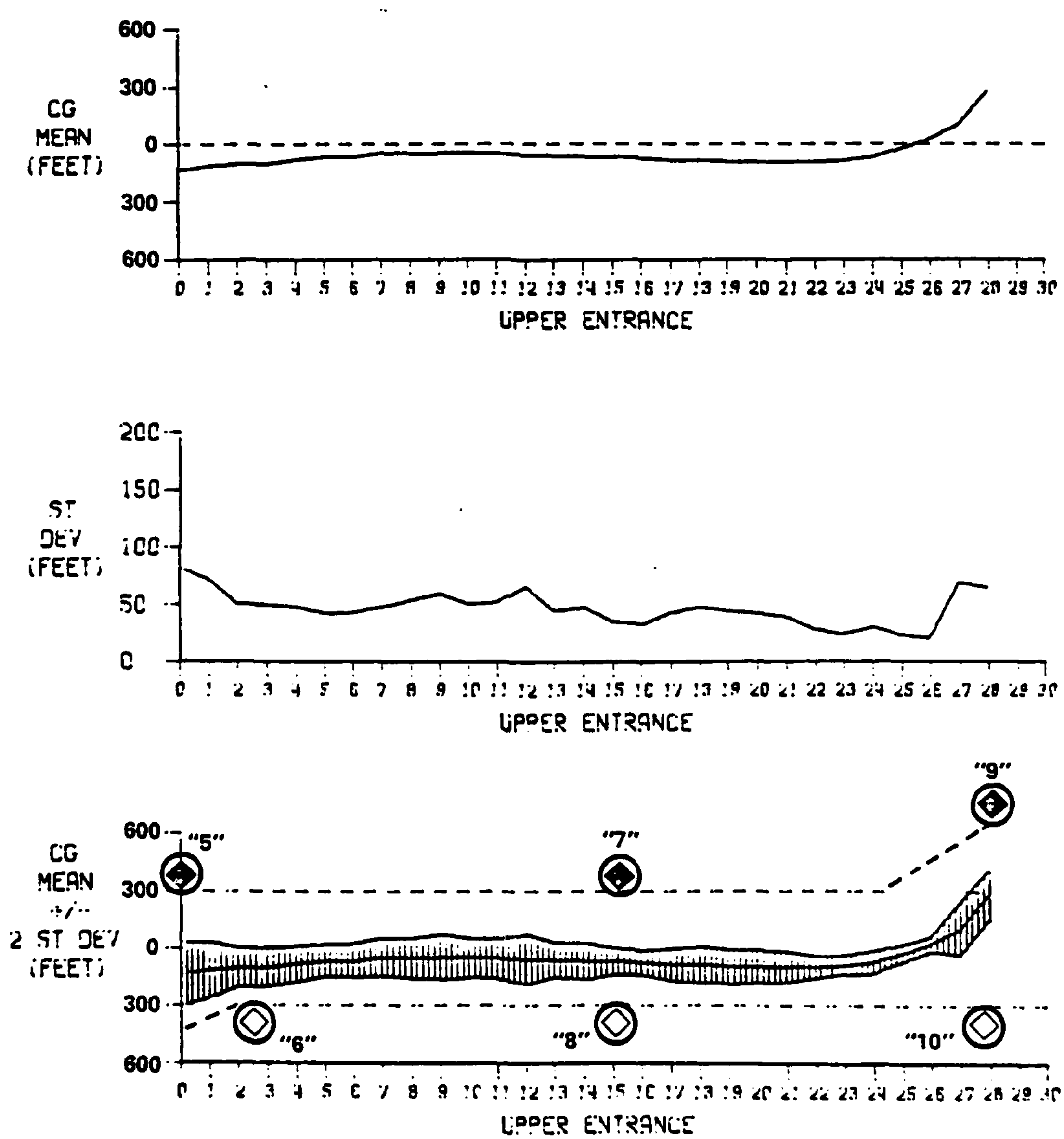

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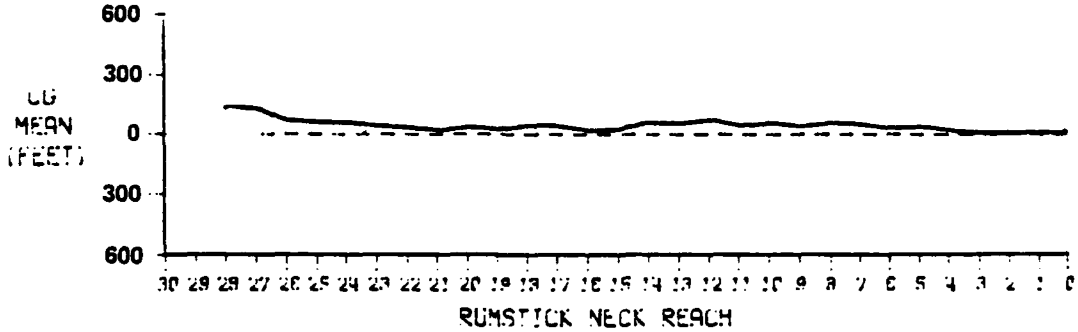

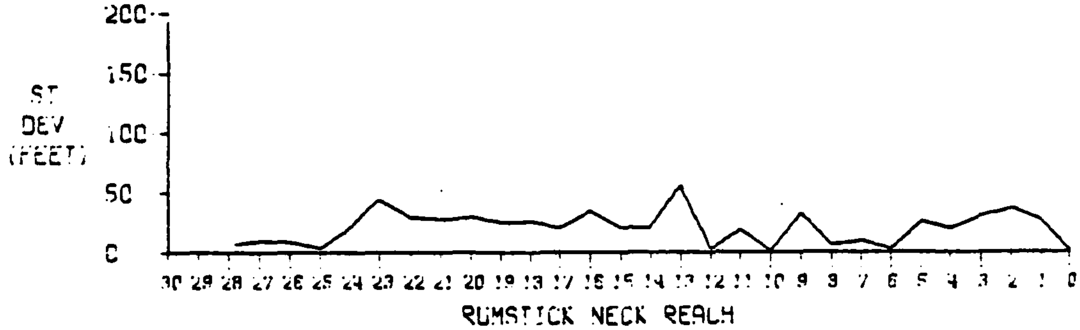

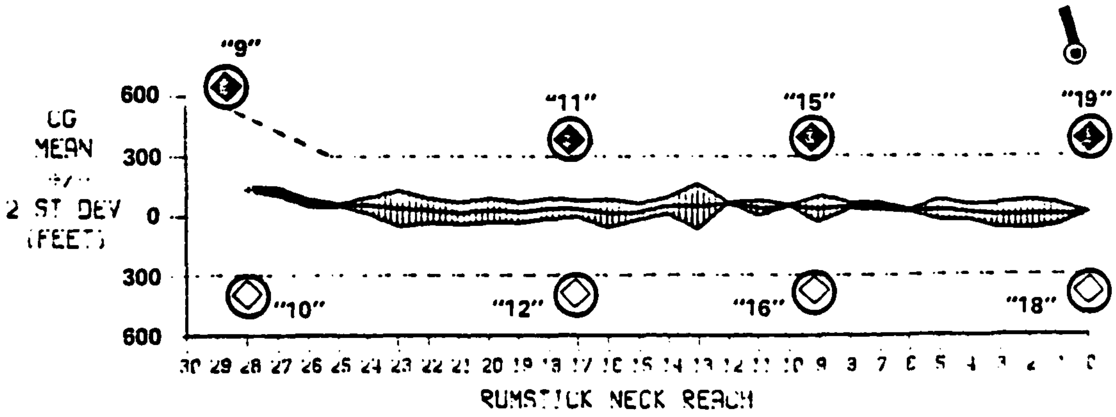

AD-A154 428 AIDS TO NAVIGATION PRINCIPAL FINDINGS REPORT: 2/2
IMPLEMENTATION AS A TEST OF..(U) ECLECTECH ASSOCIATES
INC NORTH STONINGTON CT K L MARINO ET AL. APR 85
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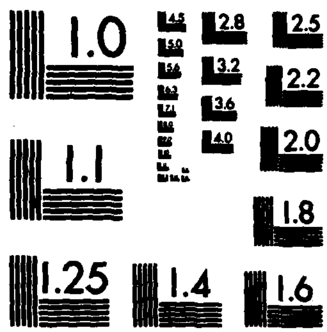
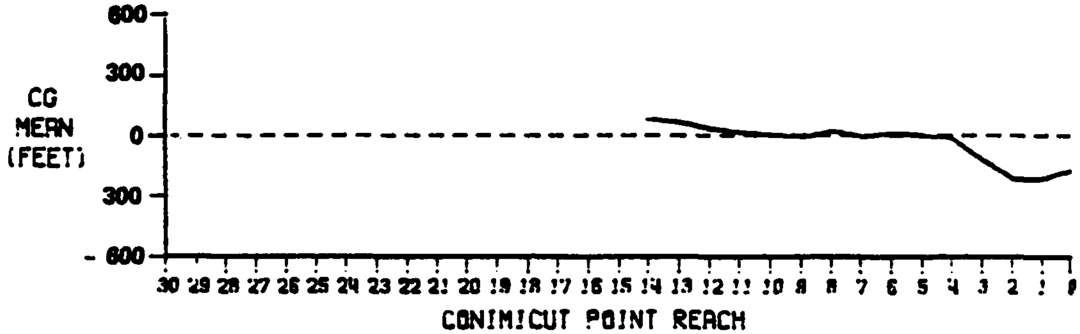
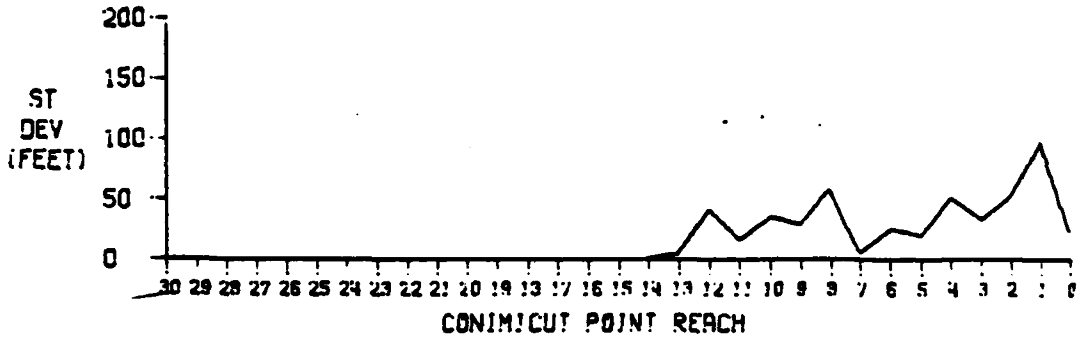
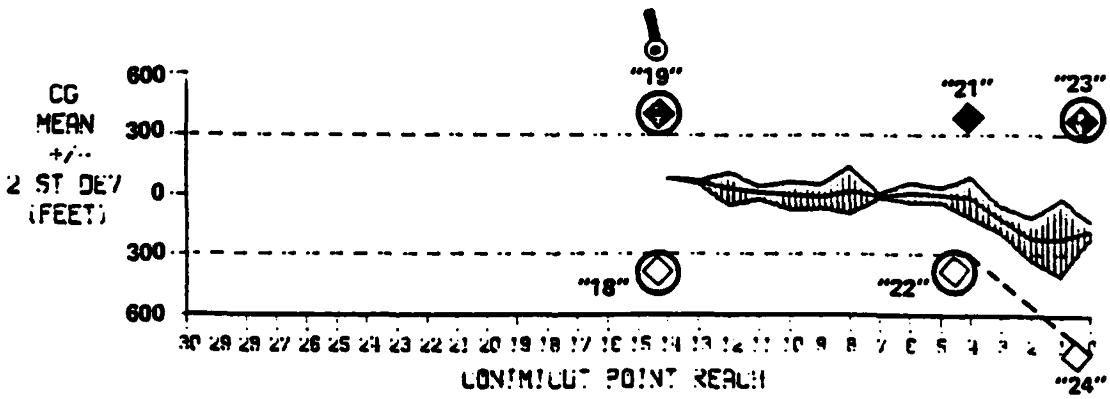


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

POST-CHANGE-DAY







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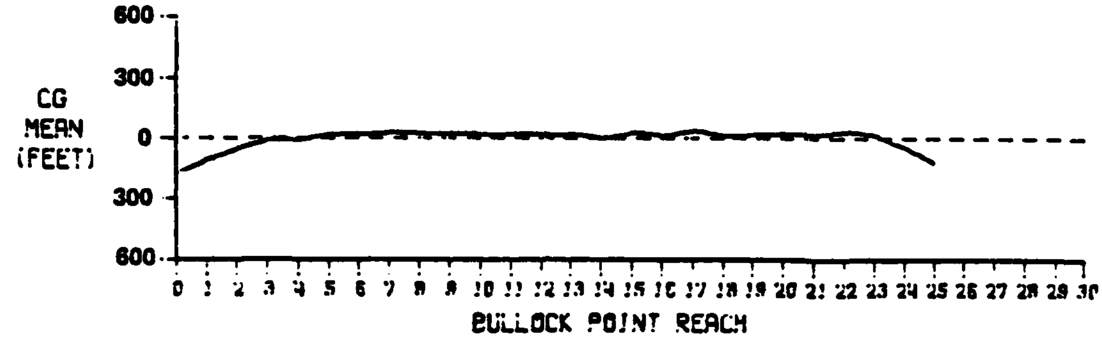

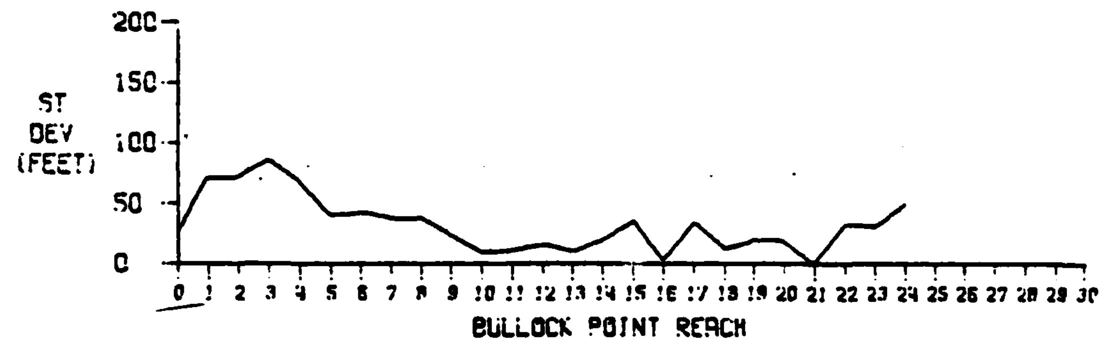

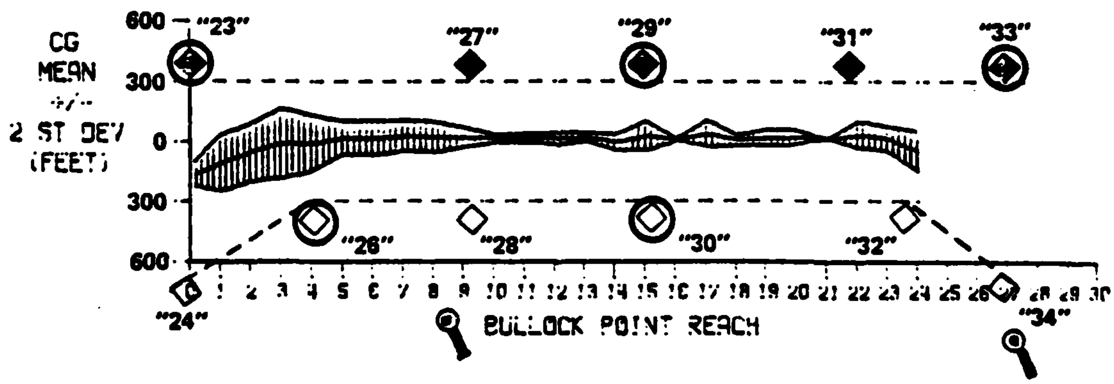

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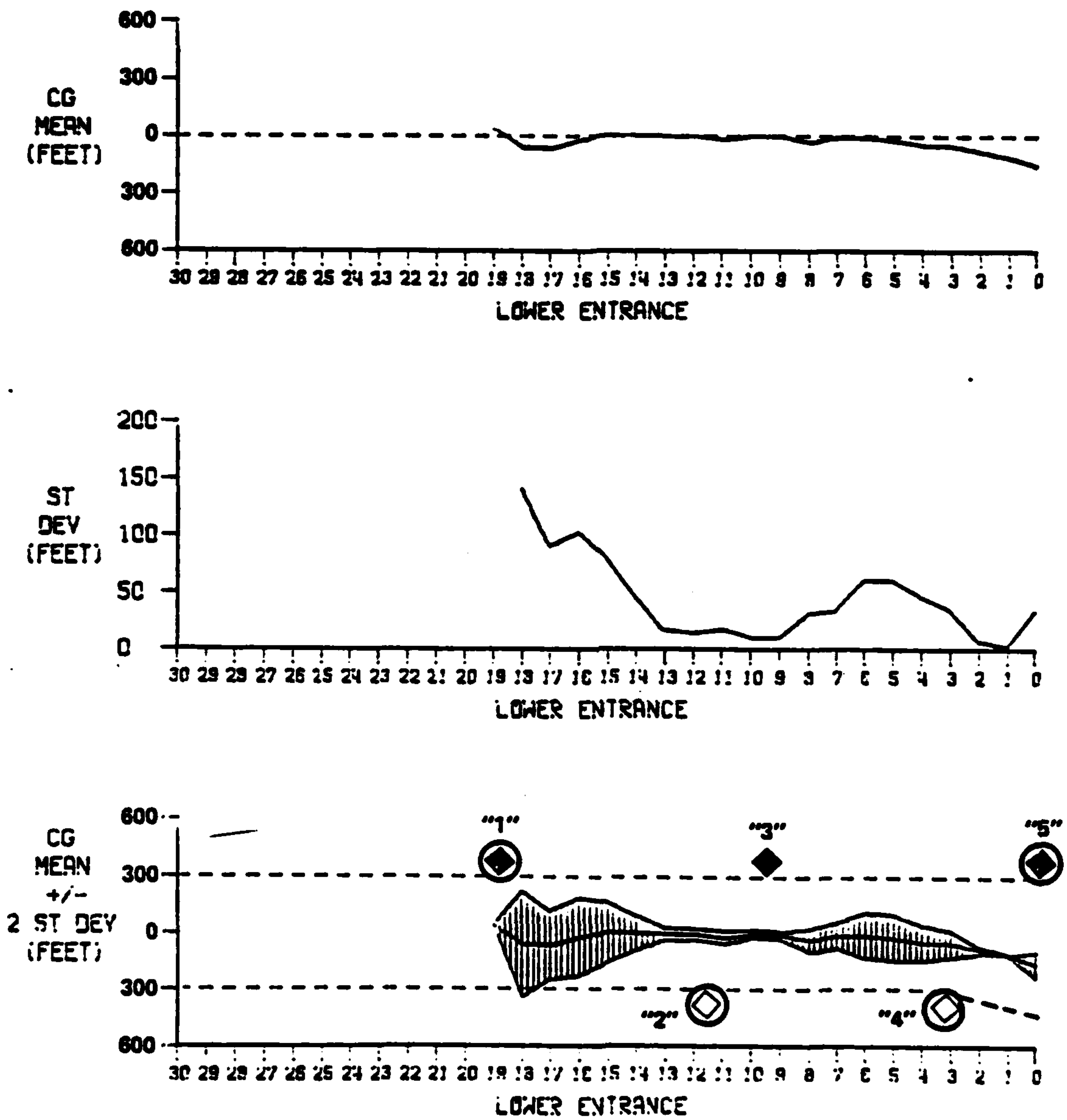

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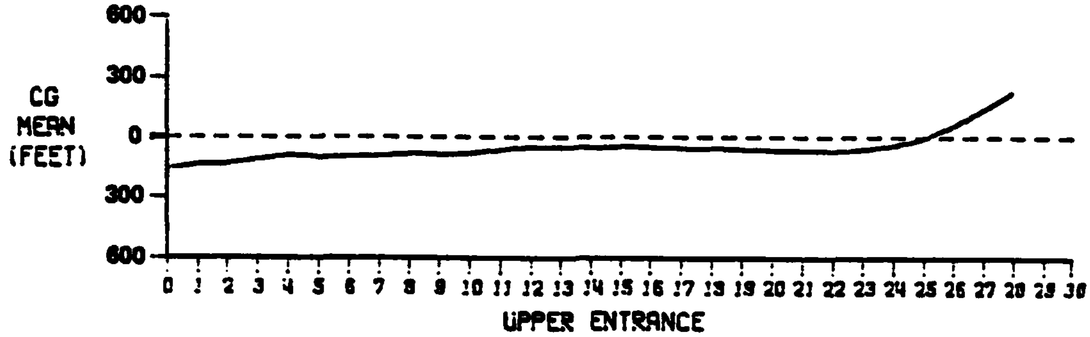

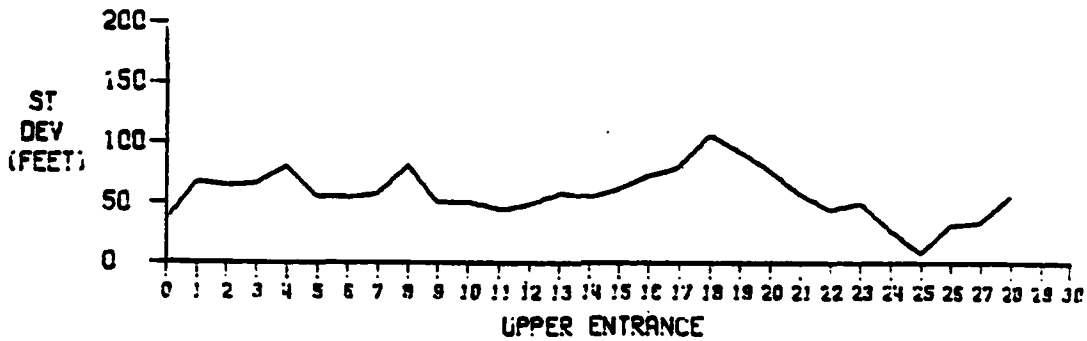

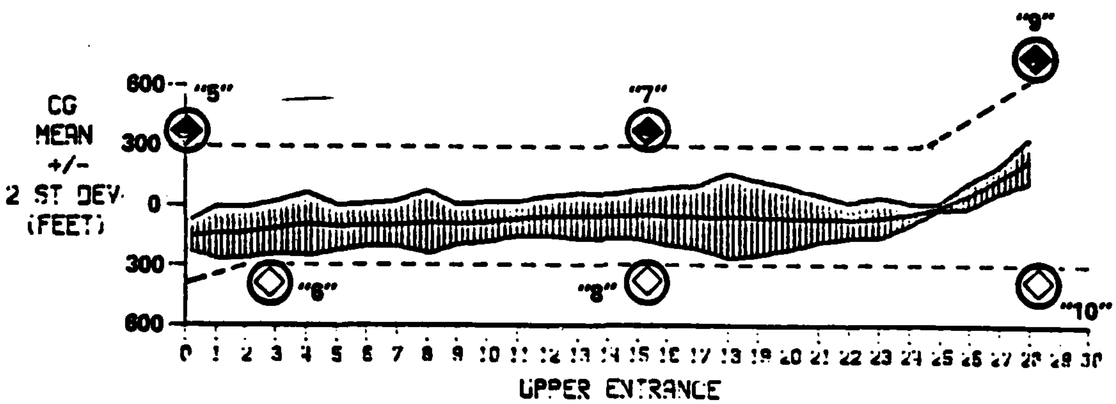

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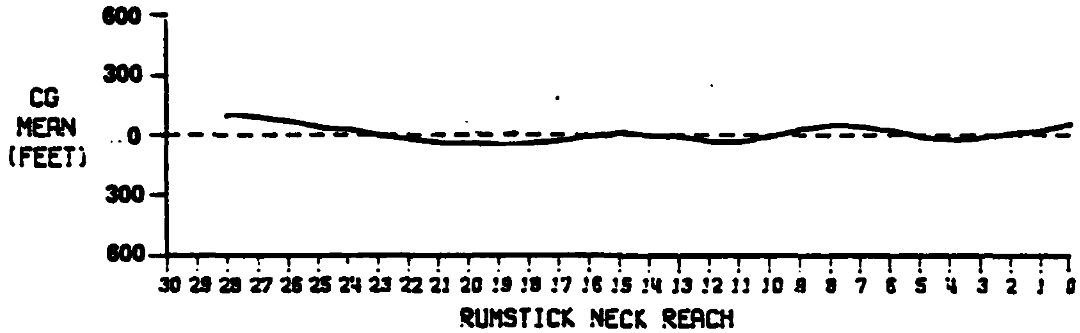

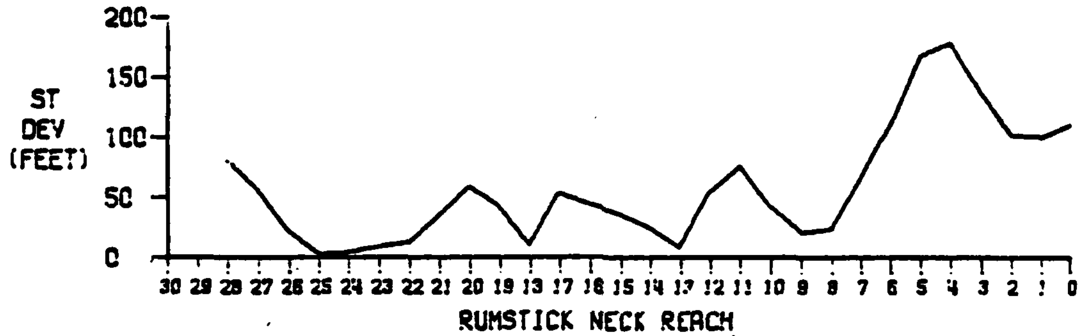

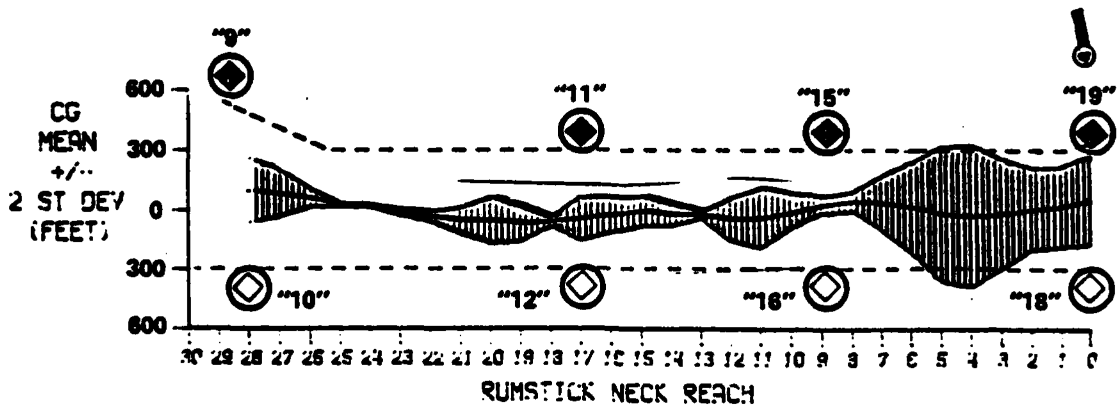

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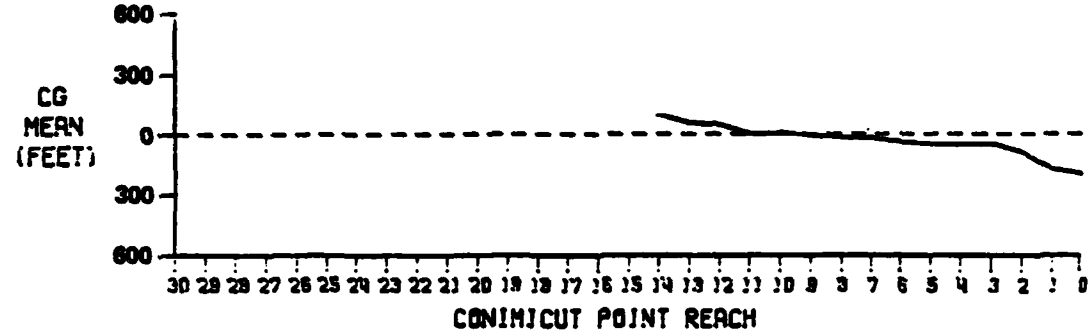

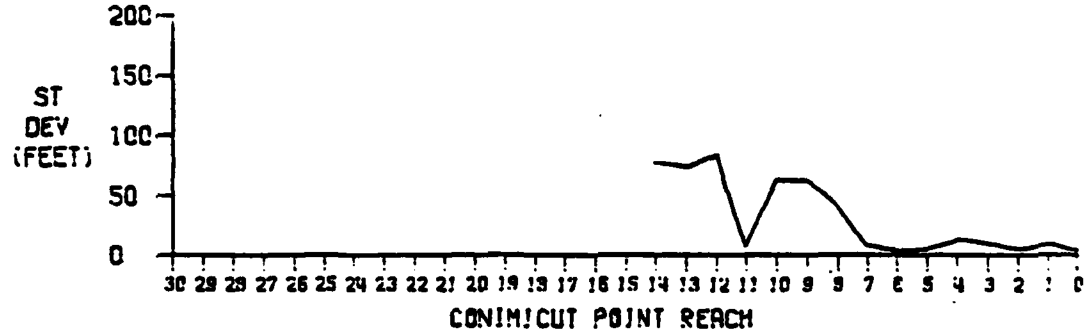

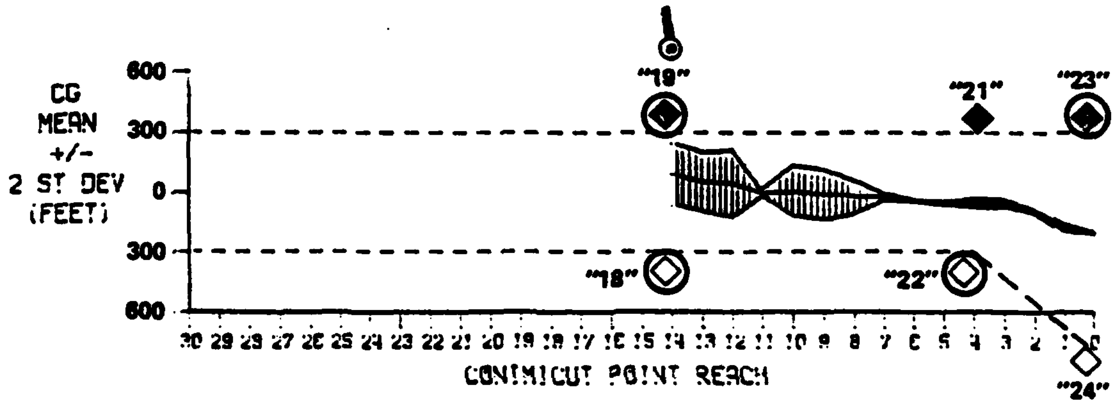

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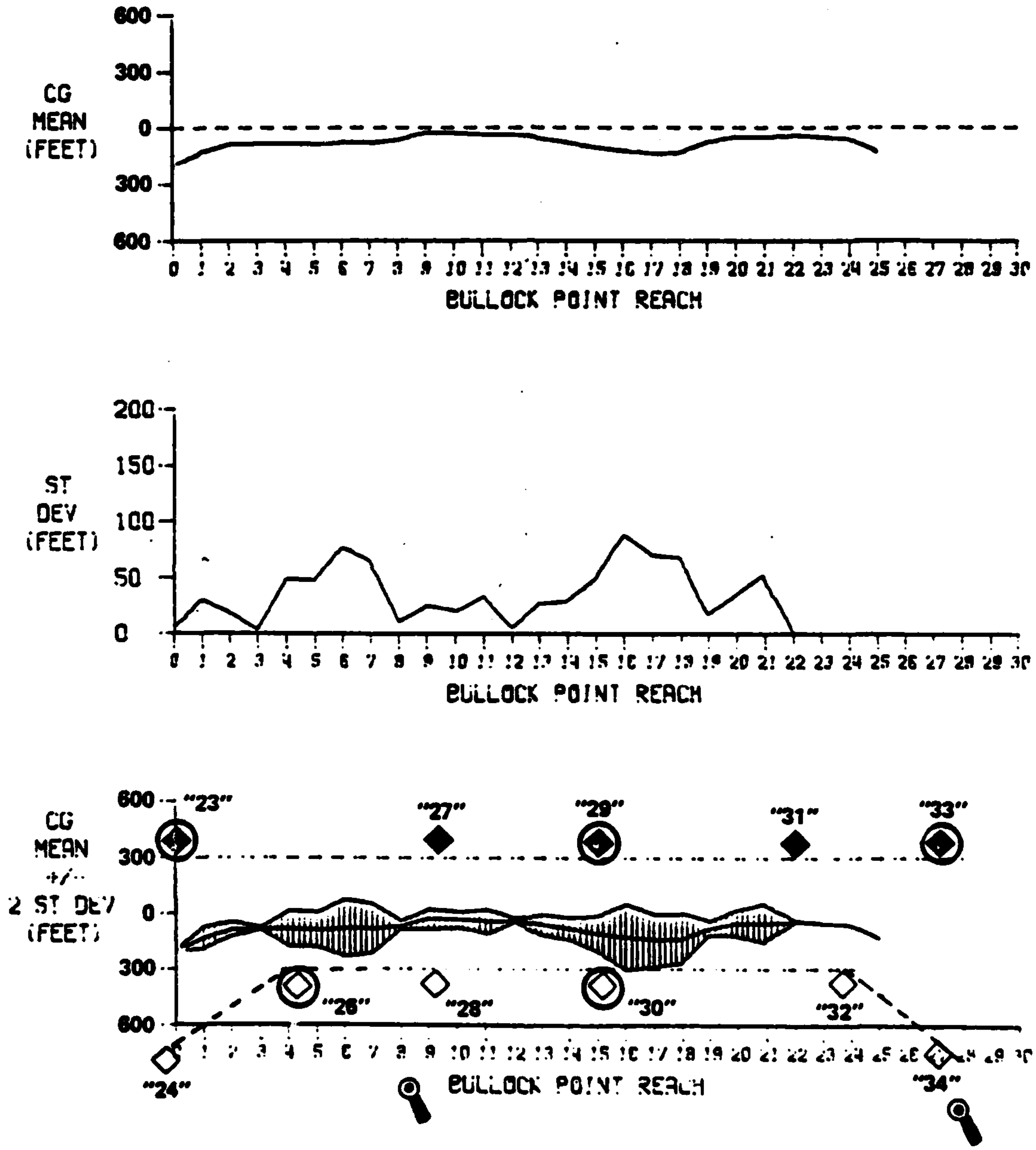

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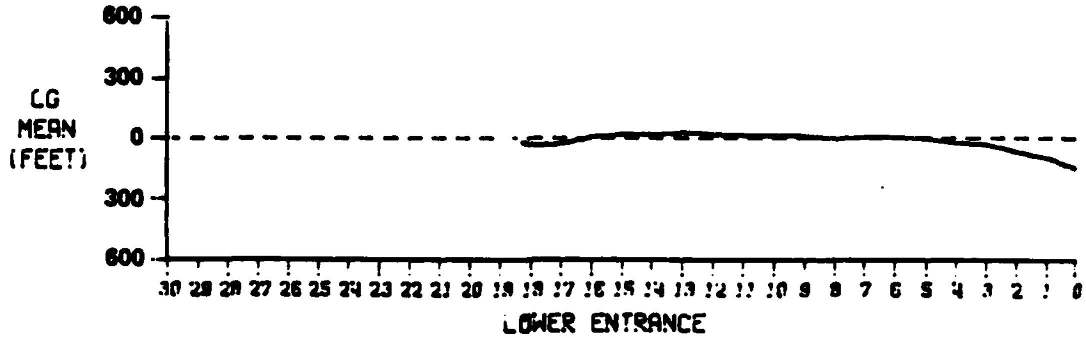

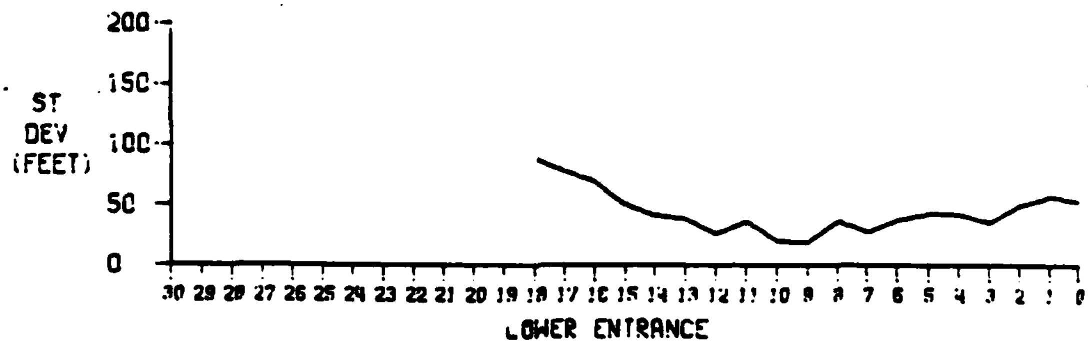

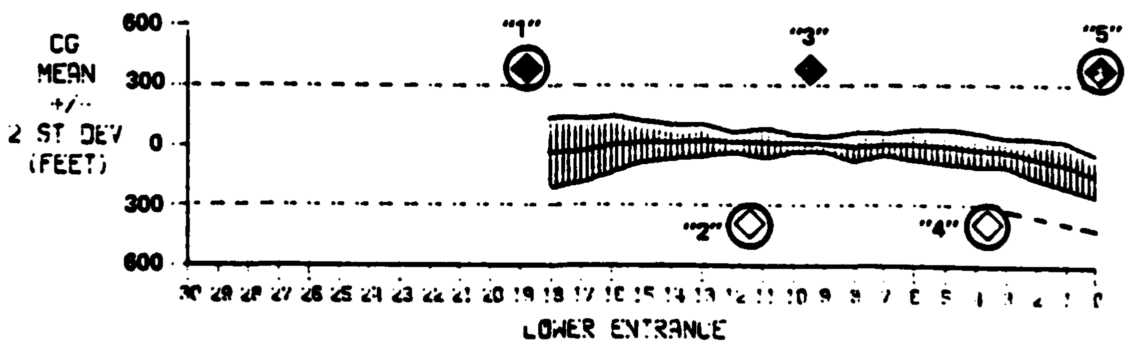

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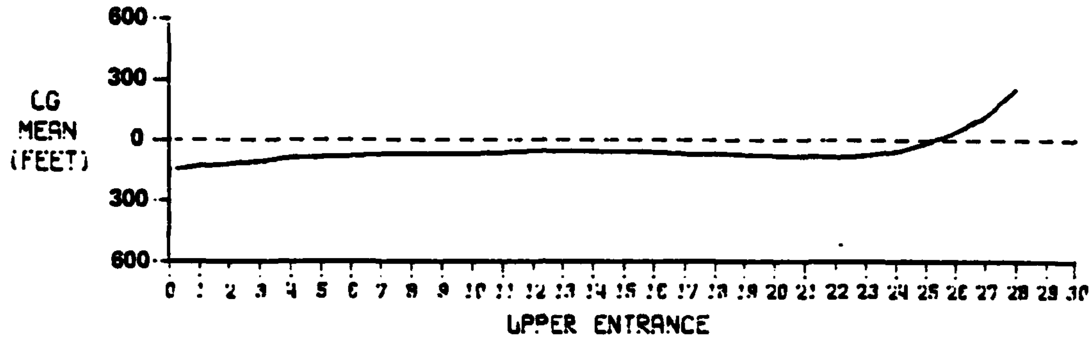

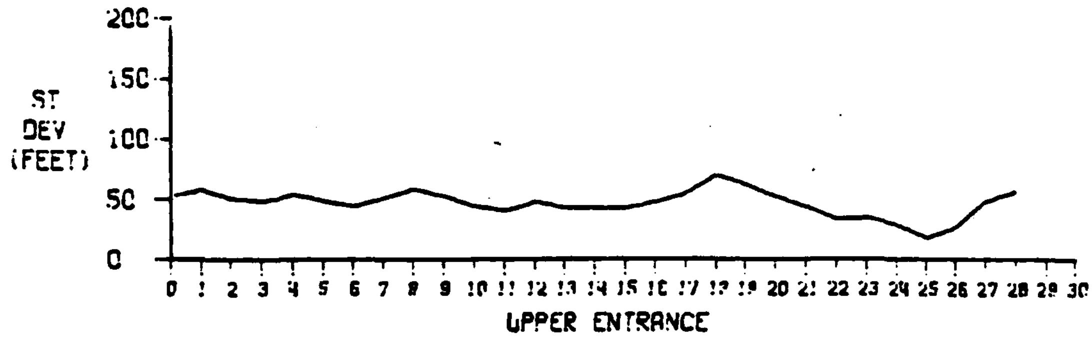

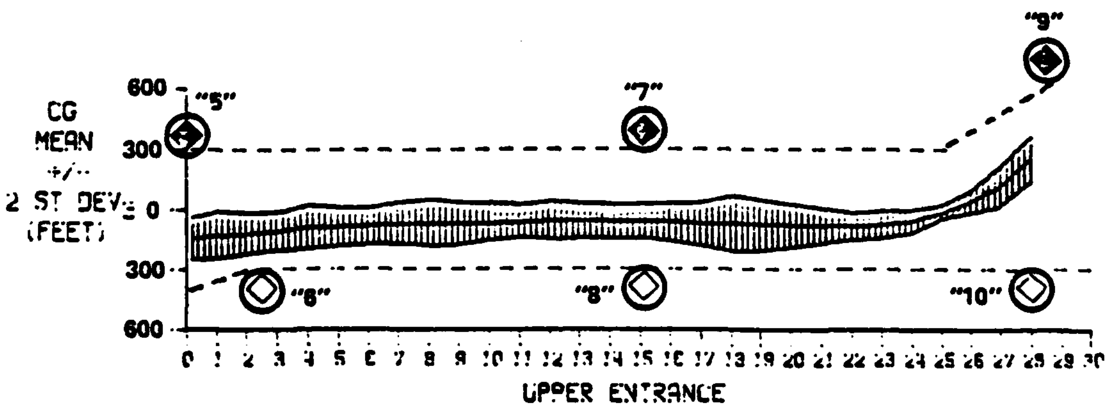

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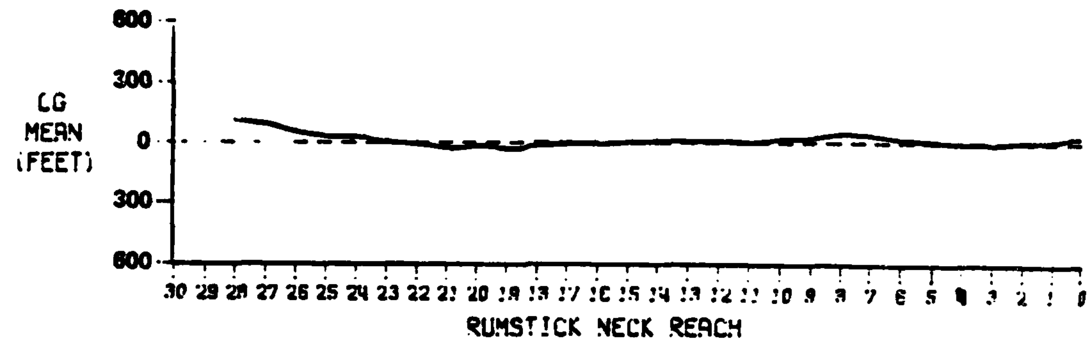

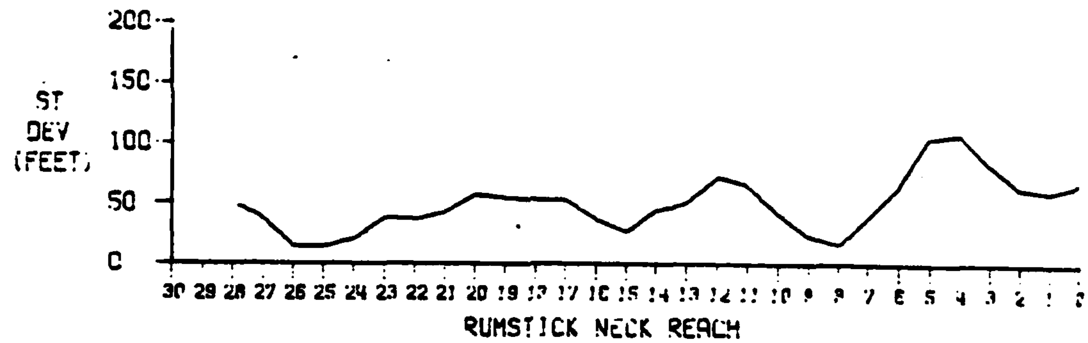

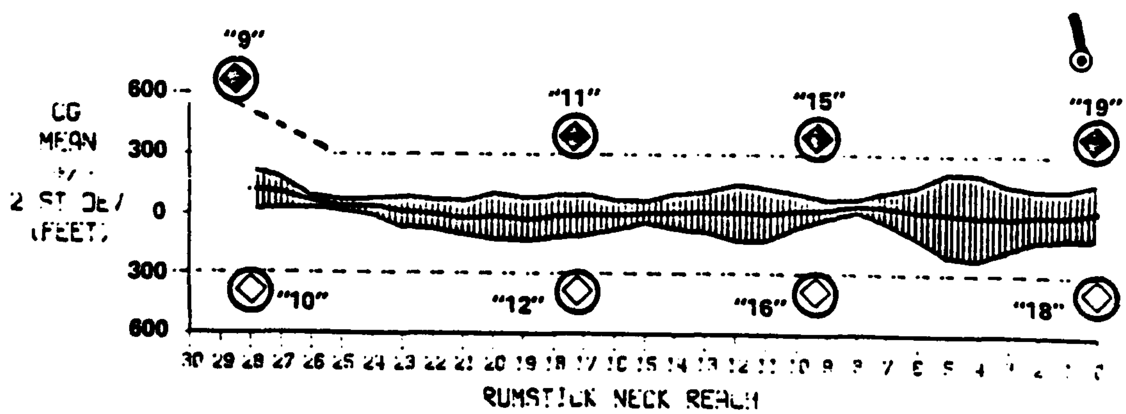

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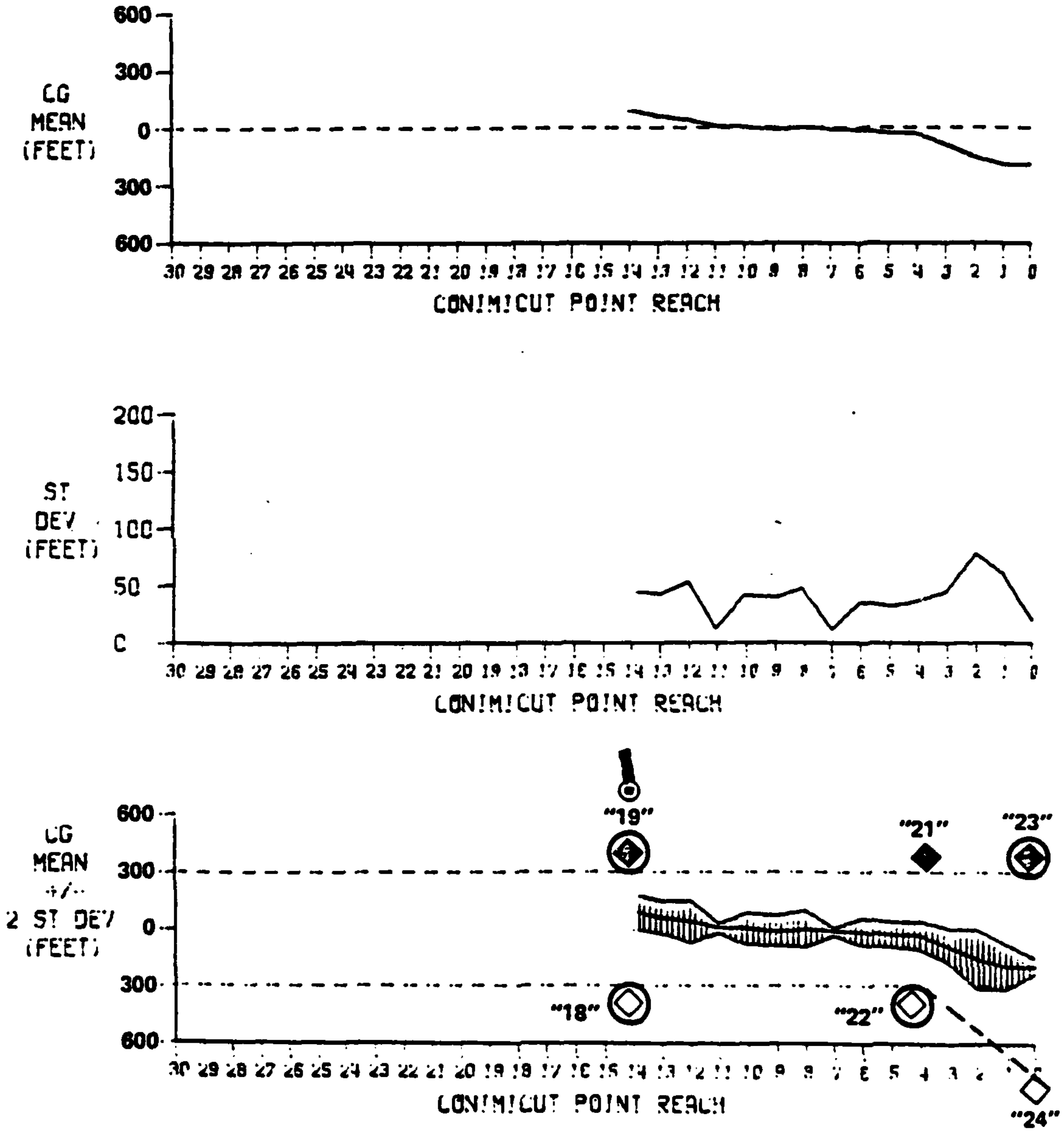

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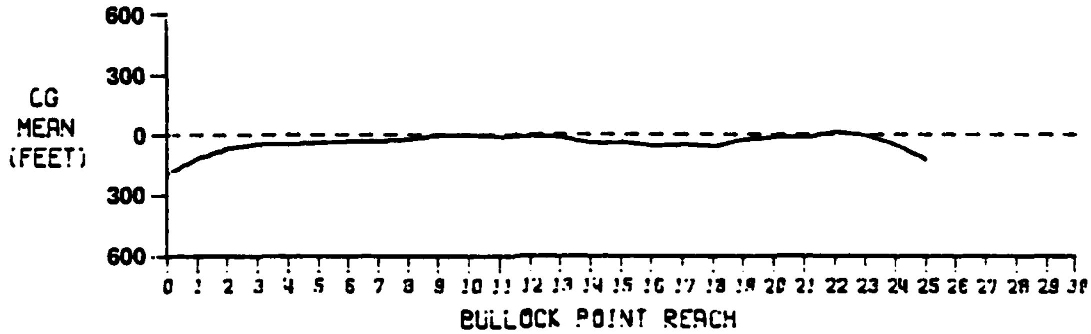

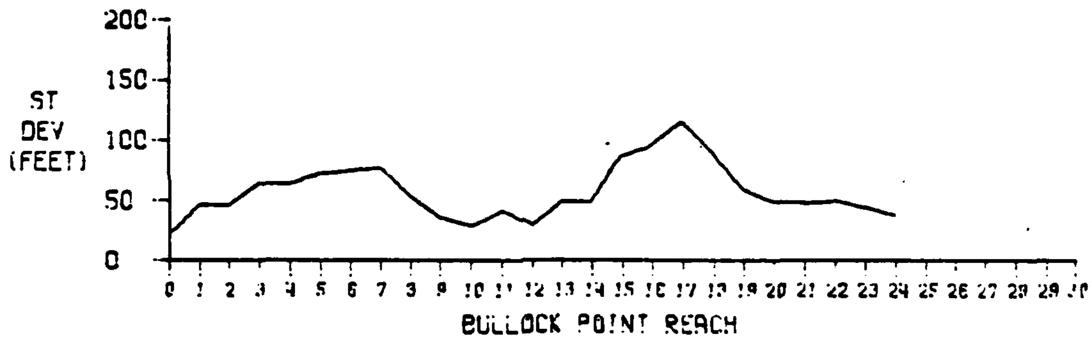

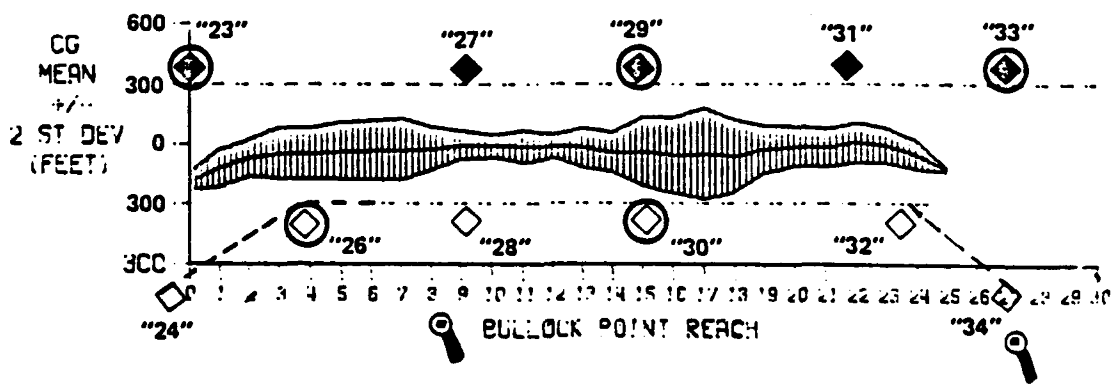

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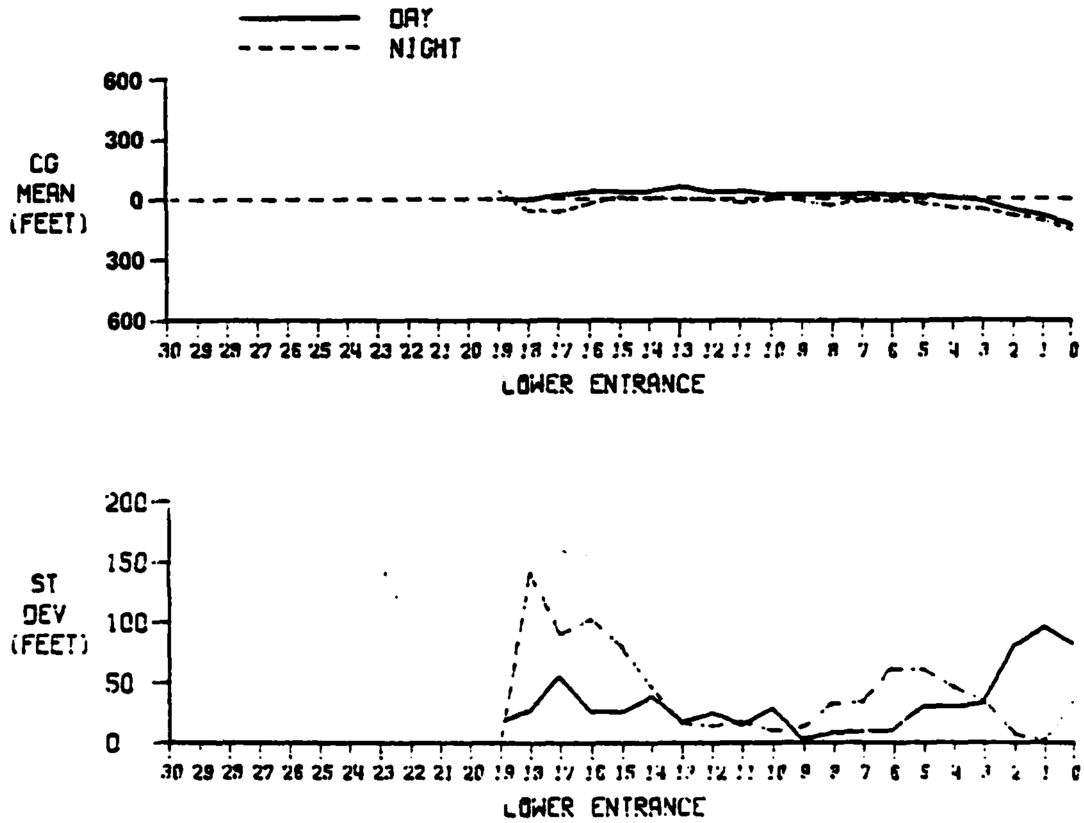

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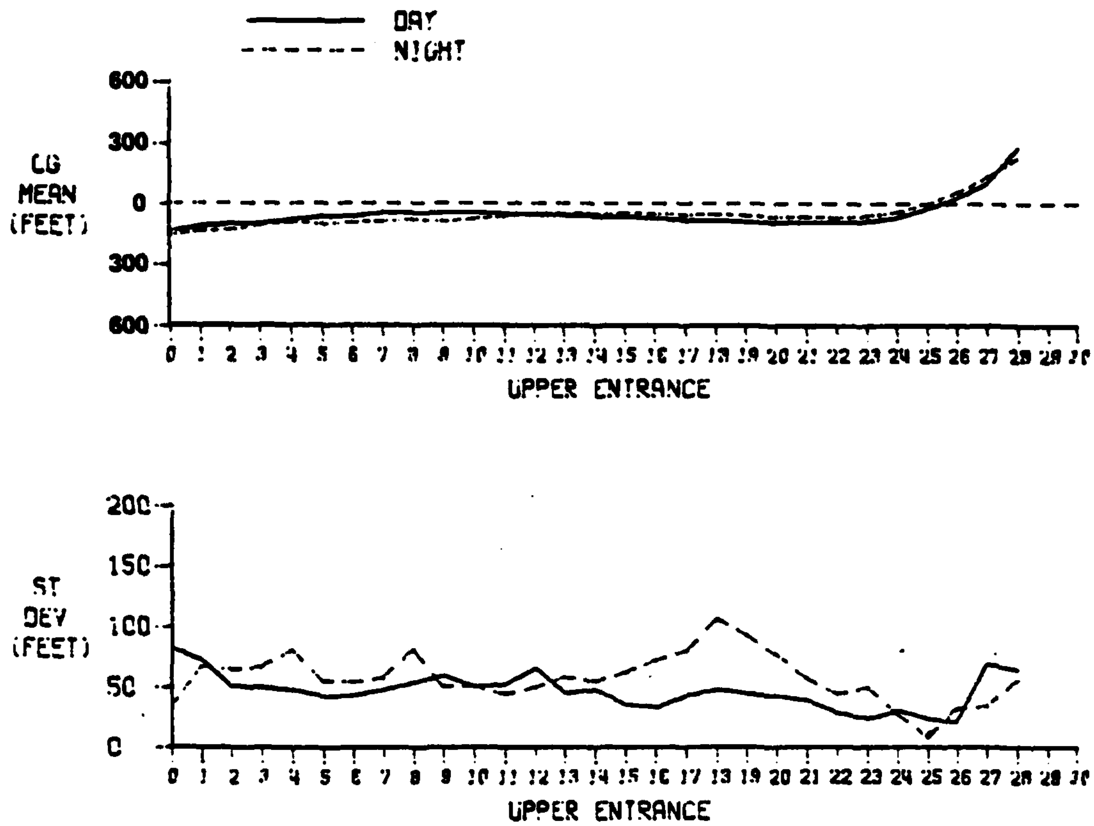

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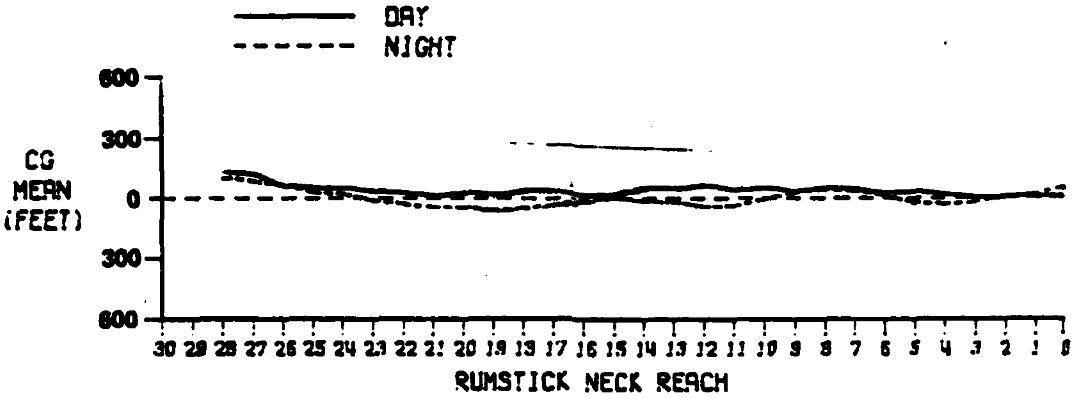

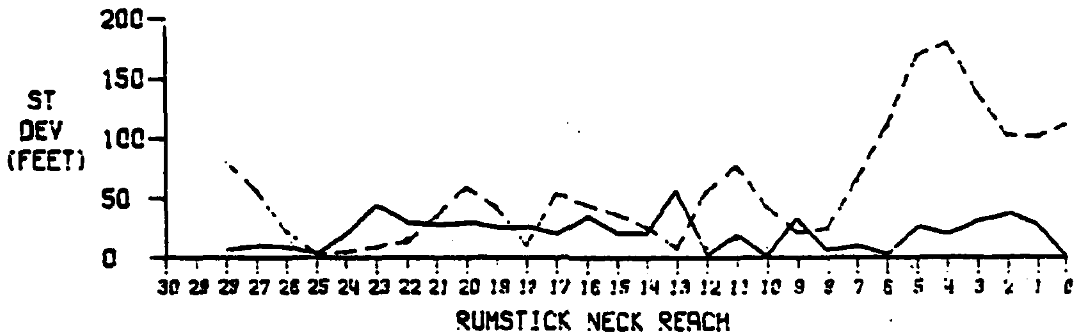

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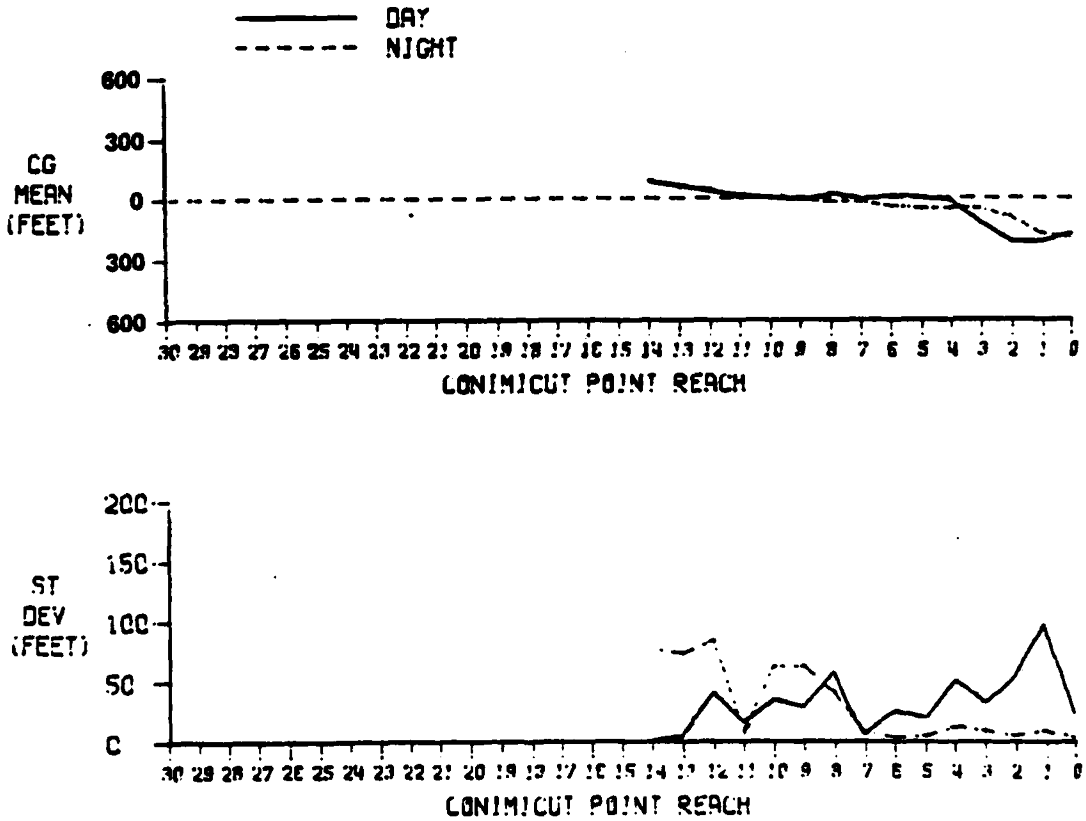

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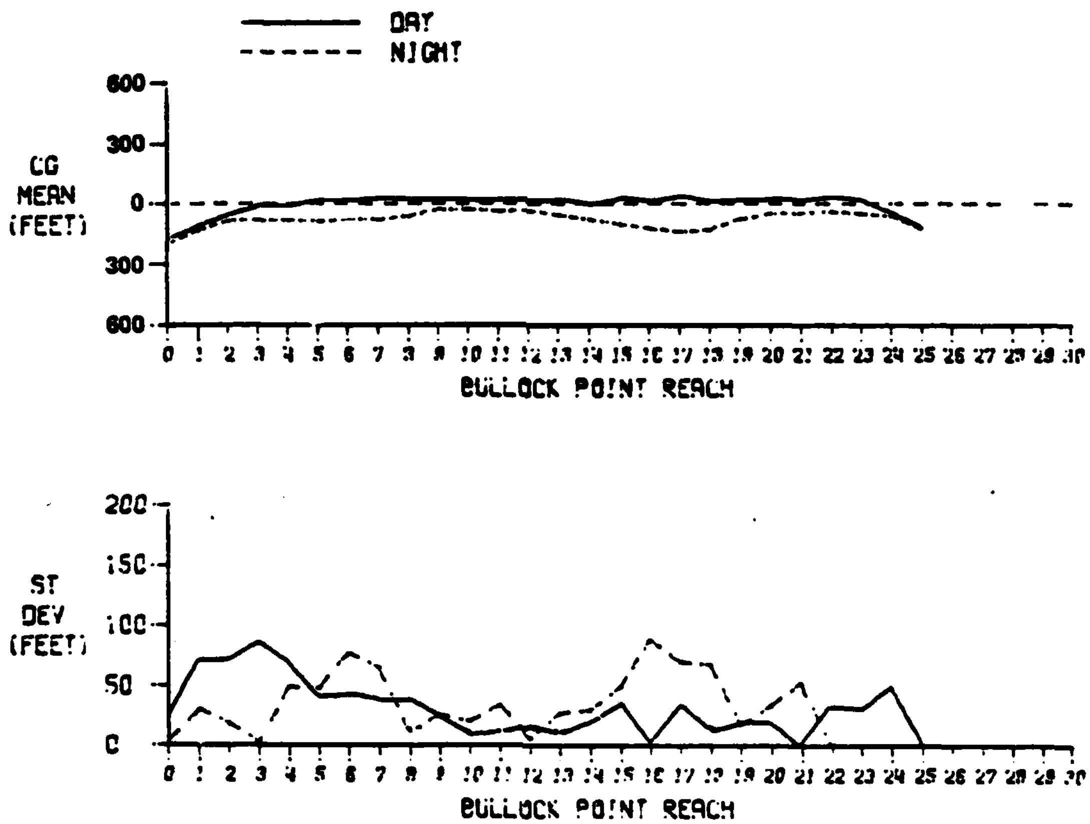

BIBLIOGRAPHY

Bertsche, W.R., M.W. Smith, K.L. Marino and R.B. Cooper. "Draft SRA/RA Systems Manual for Restricted Waterways." CG-D-77-81, U.S. Coast Guard, Washington, D.C., February 1982. NTIS AD-A113236.

Bertsche, W.R. and R.C. Cook. "Analysis of Visual Navigation Variables and Interactions." U.S.Coast Guard, Washington, D.C., October 1979.

Grant, G. and J. Moynehan. "Aids to Navigation Validation II/ Implementation: Preliminary Observations and Data Analysis." U.S. Coast Guard, Washington, D.C., October 1979.

Gynther, J.W. and R.B. Cooper. "At-Sea Data Collection Plan for Prototype Implementation of Aid System Design Guidelines." U.S. Coast Guard, Washington, D.C., April 1982.

Gynther, J.W. and G.E. Grant. "Experimental Procedures for Prototype Implementation of Aid System Design Guidelines." U.S. Coast Guard, Washington, D.C., July 1982.

Marino, K.L., J.D. Moynehan, J. Multer, and M.W. Smith. "Aids to Navigation Implementation At-Sea Postimplementation Draft Principal Findings." Washington, D.C., October 1984.

Marino, K. and J. Moynehan. Memorandum to LT W. Ridley: "Plan for Second Implementation At-Sea Data Collection." Memorandum, 7 May 1984.

Moynehan, J.D.. "Aids to Navigation Implementation At-Sea Preimplementation Draft Principal Findings." U.S. Coast Guard, Washington, D.C., September 1983.

Smith, M.W., K.L. Marino, J. Multer, and J.D. Moynehan. "Aids to Navigation Principal Findings Report: Validation for a Simulator-Based Design Project." CG-D-06-84, U.S. Coast Guard, Washington, D.C., July 1984.

Smith, M. Memorandum to LT W. Ridley. "Air Arrangments in Rumstick Neck Reach, Selection criteria, and the AN Design Manual." August 22, 1983.

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